

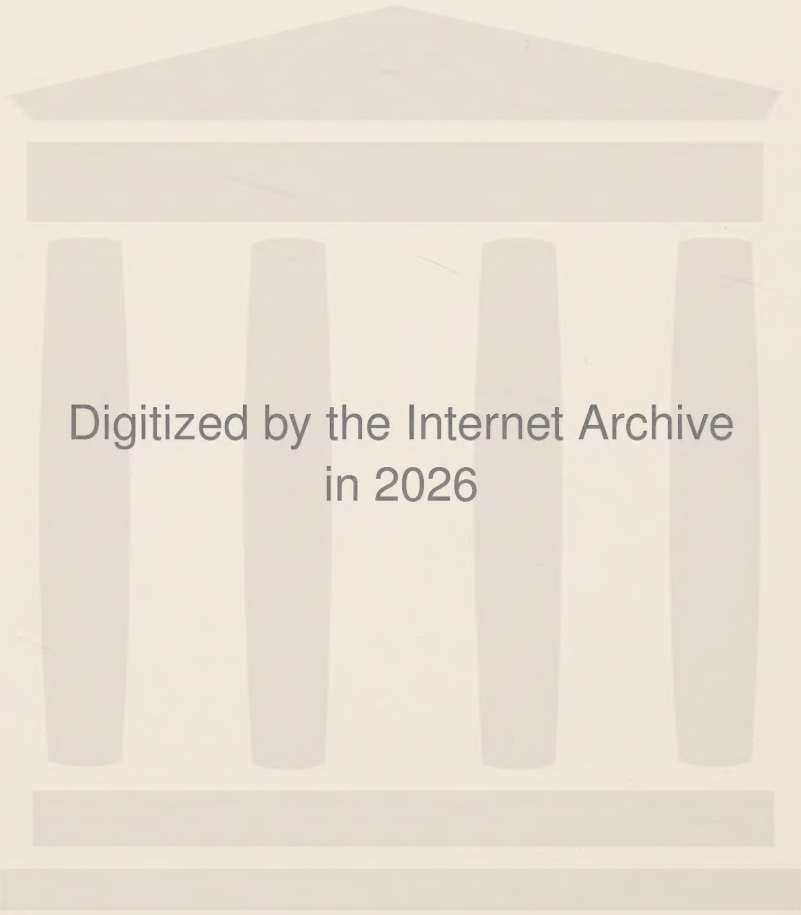
Maxillary Ostial Function Tests and Diagnostic Ultrasonography of Paranasal Sinuses

An Experimental and Clinical Study

Magnus Jannert

Malmö 1982

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MAXILLARY OSTIAL FUNCTION TESTS AND DIAGNOSTIC ULTRASONOGRAPHY
OF PARANASAL SINUSES
AN EXPERIMENTAL AND CLINICAL STUDY

by
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To Lena, Anna and Terese

The present thesis is based on the following papers which will be referred to in the text by their Roman numbers:

- I Ivarsson, A., Andréasson, L., Jannert, M. & Erlandsson, B.
Patency tests of the maxillary ostium - Model experiments.
Acta Otolaryngol (Stockh) 1982. Accepted for publication.

- II Jannert, M., Andréasson, L., Ivarsson, A. & Nielsen, A.
Patency of the maxillary sinus ostium in healthy
individuals.
Acta Otolaryngol (Stockh) 1982. Accepted for publication.

- III Jannert, M., Andréasson, L. & Ivarsson, A.
Studies of the maxillary ostial function in cases with
maxillary pain, intrasinus cysts and chronic sinusitis.
Acta Otolaryngol (Stockh) 1982. Accepted for publication.

- IV Holmer, N-G., Andréasson, L. & Jannert, M.
New ultrasonic equipment for diagnostic screening of
paranasal sinuses - An experimental study.
Acta Otolaryngol (Stockh), Suppl. 389.

- V Jannert, M., Andréasson, L., Holmer N-G. & Lörinc, P.
A comparison between different ultrasonic display
techniques, radiography and invasive control for different
disorders of the paranasal sinuses.
Acta Otolaryngol (Stockh), Suppl. 389.

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DEFINITIONS

Rhinomanometry: The airway resistance ($\text{cm H}_2\text{O}/1000 \text{ cm}^3.\text{s}^{-1}$) of the single nasal cavity is studied during spontaneous breathing. Pressure and air-flow are measured simultaneously.

Pressure = P_n and P_s : Pressures ($\text{mm H}_2\text{O}$) created in a nasal cavity and within a maxillary sinus during nasal breathing.

Air-flow = $\dot{V}_o$: Rate of air-flow ($\text{cm}^3.\text{s}^{-1}$) through the maxillary ostium during nasal breathing.

Differential pressure = P_o : Pressure difference ($\text{mm H}_2\text{O}$) between nose and sinus during spontaneous nasal breathing.

Ostial resistance = R_o : The quotient of the differential pressure and air-flow $R_o = \frac{P_o}{\dot{V}_o}$ ($\text{mm H}_2\text{O}/1000 \text{ cm}^3.\text{s}^{-1}$).

Equivalent ostial diameter: The differential pressure recorded at a constant air-flow ($\dot{V}$) of $2.0 \text{ cm}^3.\text{s}^{-1}$ or $16.7 \text{ cm}^3.\text{s}^{-1}$ is converted into the equivalent ostial diameter (mm) from a log-log diagram obtained from model experiments with known ostial diameters.

A-mode: Data presentation using Amplitude modulation.

B-mode: Data presentation using Brightness modulation.

Transducer pulse: The initial pulse wave within a depth of 1 cm read on the time scale.

Air-mucosa echo (AME): The first real echo in an air-filled sinus. An AME within 1.5 cm from the peak of the transducer pulse is a sign of a healthy sinus and an AME 1.5-3 cm from the peak of the transducer pulse is a sign of mucosal swelling.

Repetition echoes (RE): A series of echoes equally spaced but with decreasing intensity, caused by rebounding of the ultrasound pulse between two strongly reflecting boundaries.

Back wall echo (BWE): A single prominent echo at a distance of 4-6 cm (frontal sinus 2-3 cm) from the peak of the transducer pulse. The BWE is an indication of secretion.

Double echo (DE): An echo consisting of a pair of peaks at a distance of 4-6 cm from the transducer peak. The DE is an indication of a cyst within the sinus.

PURPOSES OF THE INVESTIGATION

The purposes of the studies (papers I-V) were as follows:

- I To evaluate three different maxillary ostial patency test methods (simultaneous pressure recording in nose and sinus, simultaneous air-flow and differential pressure recording between nose and sinus and pressure recording at a constant artificial air-flow into the sinus) in model experiments.
- II To evaluate the possibilities and limitations of these methods on a series of healthy volunteers.
- III To test the maxillary ostial function with these methods in patients with maxillary pain, intrasinusal cysts and chronic sinusitis.
- IV To evaluate three different ultrasonic display systems (oscilloscope, light emitting diodes and gas discharge display) in model experiments and on human maxillary sinuses.
- V To find and evaluate the most efficient display system for clinical judgement of sinusal content.

INTRODUCTION

The air-containing paranasal sinuses lined with an epithelial ciliated mucosa are, during physiological conditions, connected to the atmosphere via the ostium. The air in the sinuses is continually exchanged during normal breathing (Proetz, 1932). Disturbances of the air-exchange is of great importance in the pathogenesis of paranasal sinus infections and a re-establishment of a patent ostium is a pre-requisite for recovery (Aust & Drettner, 1974a).

The first study on ostial function was published by Braune & Clasen (1877) and since then different methods have been used in order to evaluate the functional state of the maxillary ostium. This has been performed on sinus models as well as on human sinuses in healthy and pathological conditions. As far as we know, no method directly designed to evaluate the ostial airway resistance has been used. Flisberg (1966) described a method for estimating the airway resistance of the Eustachian tube for standardized conditions in cases with perforated eardrums. The air-flow through, and the pressure difference across, the tube needed to induce this flow was used in the equation $R = \frac{P}{\dot{V}}$ (in cm H₂O/1000 cm³.s⁻¹) to express the resistance. With a modification of this method we found it interesting to clarify the ostial airway resistance during nasal breathing and compare it to other well known tests in model experiments, on healthy individuals as well as in diseased sinuses.

The majority of infectious diseases in the nose and paranasal sinuses produce similar signs and symptoms (Axelsson & Runze, 1976) and the methods most frequently used for diagnostic purposes are apart from clinical examination, radiography, antral aspiration, sinus lavage and sinoscopy. Since Keidel (1947) mentioned the possibility of using ultrasound for paranasal sinus diagnostic purposes several studies have been published on this subject. However, in almost all earlier studies technically complicated equipment adapted from cardiological or obstetric purposes has been utilized. Due to this ultrasonography has become clinical routine in a few centers only.

Simplified mobile ultrasound equipment for screening purposes was separately described by Jannert et al. (1980) and Revonta (1980).

The reflected echoes are displayed on a single row of light emitting diodes. In order to find the most suitable equipment for separating different sinusoidal contents two other ultrasound display systems (an oscilloscope and a gas discharge display) were used. All three display techniques with a specially constructed amplification mode were tested in model experiments and in clinical material.

EARLIER METHODS

OSTIAL FUNCTION TESTS

The function of the maxillary ostium has been a source of interest since Braune & Clasen (1877) made the first intra-maxillary pressure recording. Many different methods have been used to test the functional state of the maxillary sinus ostium and they can be divided as follows:

Measurements during spontaneous breathing

Air pressure recording in the maxillary sinus after puncture was performed by e.g. Kerekes (1935) with a water manometer, Flottes et al. (1960) with an amyl alcohol manometer, and Drettner (1961) with an electromanometer. Pfretschner & Loibl (1971) simultaneously recorded the respiratory air-flow and pressure changes within the maxillary antrum and studied the effects of breathing and the influence of septal deviation on the pressure changes within the sinuses.

Air pressure recording in the maxillary sinus and the nasal cavity can be performed either simultaneously (Proetz, 1932; Drettner, 1965a) or consecutively (Rantanen & Kortekangas, 1971). Drettner measured pressure changes within the sinus via a Lichtwitz needle and within the ipsilateral nasal cavity with a catheter placed near the ostium. Kortekangas (1970) measured the differential pressure between the sinus and the contralateral nasal cavity. Rantanen & Kortekangas (1971) consecutively recorded the sinus pressure changes and the contralateral nasal cavity pressure changes using anterior rhinomanometry.

Air-flow measurements within the maxillary sinus were performed by Müsebeck & Rosenberg (1978) with a hot film anemometer after puncture of the sinus through the canine fossa. After this differential pressure recording between the contralateral nasal cavity and the sinus was performed.

Measurements of the airway resistance between the nasal cavity and the frontal sinus were described by Andréasson et al. (1977).

The air-flow through the naso-frontal duct and the differential pressure between the ipsilateral nasal cavity and frontal sinus was simultaneously measured during nasal breathing in a series of trephined frontal sinuses. The airway resistance of the naso-frontal duct was expressed as

$$R = \frac{\text{diff. pressure nose-sinus}}{\text{air-flow}} \quad \text{in cm H}_2\text{O}/1000 \text{ cm}^3.\text{s}^{-1}.$$

Xenon wash-out methods were used by Kirchner (1974) and Strechenbach et al. (1979). The sinus was filled with $^{133}\text{Xenon}$ and the declining radioactivity indicated the ostial function.

Measurements during artificial pressure application

The ostial forcing pressure levels for air were recorded by Flottes et al. (1960) using "ventilometric equipment". This consisted of a water manometer and a syringe with a 3-way valve and was used on patients with chronic sinusitis. After lavage they infused air into the sinus not tolerating higher sinus pressure levels than 200 mm H₂O in order to avoid air embolism. They found forcing pressure levels of 30-140 mm H₂O after sinus lavage when increasing the sinus pressure but could not force the ostium open when they decreased the air pressure level within the sinus to -200 mm H₂O. In cases with maxillary sinusitis Mannet al. (1975) used an air pressure chamber with which he could create relative over- and underpressures in the sinus in order to find the forcing pressure levels for air. He invariably found the highest forcing pressure level in the naso-sinusal direction. Bachmann (1978) applied known over- and underpressures into the sinus in cases with maxillary sinusitis. With the use of a differential pressure transducer and an x-y recorder the time for pressure equilibration was used as an expression for the ostial function.

The functional size of the maxillary ostium was measured by Aust & Drettner (1974b) by infusion of a constant defined artificial air-flow (1-6 liters per minute) into the sinus. The pressure increase within the sinus could then be compared with a diagram created from model experiments with known ostial diameters in order to estimate the corresponding ostial diameter.

Forcing pressure levels for fluid. After puncture of the sinus Drettner (1965b) infused saline solution by slowly elevating of the saline bottle from the level of the ostium until the nose started to drip. The height in cm from the ostium to the fluid level in the bottle was expressed as the "resistance". Rantanen (1974) used the same method but refined the technique with a drop chamber and used a pump and a manometer to measure the forcing pressure level.

Resistometry. Zippel et al. (1974) described resistometry equipment for the naso-frontal duct with which either the pressure within the sinus or the flow of water through the duct could be kept constant and in that way an expression for the resistance to fluid of the ostium was obtained.

ULTRASONIC EXAMINATIONS

The first attempt to use ultrasound for diagnostic purposes in the medical field was made by Dussik (1942) who tried to evaluate the form and size of the intracerebral ventricles. This method, further developed by Leksell (1955), is an important diagnostic tool for examination of intracranial space occupying processes. The ultrasonic examination technique has during the last 40 years been used, e.g. for cardiological (Hertz & Edler, 1956), obstetrical (Sundén, 1964) and abdominal examinations (Holm, 1971).

In the field of otolaryngology the movements of the vocal cords were analysed by Hertz et al. (1970) and the method was also used for detecting secretion in the middle ear by Abramson et al. (1972).

The possibility of using ultrasound in diagnosing diseases of the paranasal sinuses was first suggested by Keidel (1947). Kitamura & Kaneko (1965) used the pulse-echo method both in model experiments and on human maxillary sinuses in an attempt to separate maxillary cancer from benign conditions. From model and human experimental studies Gilbricht & Heidelberg (1968) were able to verify secretion in the maxillary sinus by indicating a back wall echo. The method was also used by Heidelberg & Gilbricht (1969) in diagnosing frontal sinusitis.

Mann (1975) re-evaluated the use of A-mode and also described the use of B-mode data presentation in paranasal sinus examination (Mann, 1976). Furthermore, he also tested the reliability of ultrasonography against sinus puncture and found a conformity in 90% of the cases (Mann et al., 1977). Revonta (1980) compared the findings of ultrasonography (Echoview VI) and radiography against those found with sinus lavage on 170 maxillary sinuses in adults and in 130 maxillary sinuses in children. He found that ultrasonography showed a statistically significant better confidence and sensitivity than radiography.

The use of ultrasound for investigation of the paranasal sinus started in our clinic in 1978 with a Picker 80 C scanner using the A-mode for data presentation and a 2.25 MHz non-focused transducer with a crystal diameter of 13 mm (Böckmann et al.,

1981). For comparative studies, 100 consecutive patients, who consulted the ENT-department because of symptoms referable to the paranasal sinuses, were examined. The results of the roentgenological and ultrasonic examinations showed correlation in 95 % of the cases. However, the equipment used was not suitable for clinical routine examination and therefore mobile simplified pieces of equipment with different display systems (light emitting diodes, oscilloscope and gas discharge display) were developed (Jannert et al., 1980, 1981a,b; Holmer et al., 1981).

I. PATENCY TESTS OF THE MAXILLARY OSTIUM - MODEL EXPERIMENTS

METHODS

This paper describes three different methods to judge the functional state of a maxillary sinus ostial model.

Method I. Simultaneous pressure recording in the sinus and the nasal cavity model during simulated nasal breathing.

Method II. Air-flow recording through and differential pressure across the ostial model during simulated nasal breathing.

Method III. Registration of the pressure increase within the sinus model with the application of a constant artificial air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ or $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ into the sinus model.

The nasal part of the nose-sinus model was constructed of plexiglass and connected to the sinus model, consisting of a syringe and exchangeable ostial models with a length of 6 mm and with known diameters of 0.22-4.7 mm. The sinusal volume was adjustable from 2-25 cm^3 . The air pressure flow characteristic of the nasal part of the model corresponded to that of a normal human nose (Broms, 1980). The nose-sinus model was connected to a piston-pump, producing a volume change of 467 cm^3 with a speed of 10 or 20 revolutions per minute which simulates nasal breathing. With the aid of the nose-sinus model a suitable cannula of measurement has been tested in order to obtain correct pressure-flow recordings using all three methods.

RESULTS

With method I a sinu-nasal pressure relationship of 1:1 was obtained with ipsilateral nasal pressure recording. A time-lag in the pressure transmission was observed as a hysteresis on the x-y recorder when the ostial diameter was $\leq 0.6 \text{ mm}$. The hysteresis was dependent on ostial diameters, sinusal volumes and air-flow rates produced by the piston-pump.

The pressure-flow relationship, recorded with method II, was dependent only on ostial diameter, while the hysteresis was due to ostial diameter, sinusal volume and air-flow rate.

In method III a constant artificial air-flow was used and the pressure-flow relationship was found to be independent of the

sinusal volumes.

The resistance of the ostium is calculated from the equation

$$R_O = \frac{P_O}{\dot{V}_O} \text{ (mm H}_2\text{O/1000 cm}^3\text{.s}^{-1}\text{)}, \text{ where } R_O \text{ is the ostial resistance,}$$

P_O differential pressure between nose and sinus and $\dot{V}_O$ the air-flow through the ostium. As the pressure-flow characteristic in non-linear (Method II) direct comparisons of ostial resistances at different air-flow levels are impossible. A diagram was accordingly constructed from the pressure values obtained with methods II and III at defined air-flow levels as a function of known ostial diameters between 0.34 mm to 4.7 mm. From this diagram an equivalent ostial diameter can be estimated from known pressure-flow recordings on human subjects, both with methods II and III (papers II-III), thereby making direct comparisons between the methods possible.

CONCLUSIONS

Qualitative evaluation of the ostium is not possible with method I. Method II permits determination of ostial resistance $\geq 25 \text{ mm H}_2\text{O/1000 cm}^3\text{.s}^{-1}$ corresponding to equivalent ostial diameters $\leq 2.5 \text{ mm}$ at an air-flow of $2.0 \text{ cm}^3\text{.s}^{-1}$, while with method III equivalent ostial diameters (0.34-4.7 mm) can be estimated at air-flows of 2.0 and $16.7 \text{ cm}^3\text{.s}^{-1}$, respectively.

II. PATENCY OF THE MAXILLARY SINUS OSTIUM IN HEALTHY INDIVIDUALS

Many more or less physiological test methods have been used to evaluate the maxillary ostial function. Most studies have been performed on diseased sinuses. Therefore, the methods briefly described in paper I have been evaluated in a material consisting of 20 healthy volunteers (35 maxillary sinuses). Subjects were selected on the criteria that they had no history of sinusitis or recent upper respiratory tract infection, that findings of ENT examination including roentgenologic and ultrasound examinations were normal and that no abnormality was found in their blood samples.

All test procedures in this study were approved by the Committee for Ethics, University of Lund, Lund.

TEST PERFORMANCE

Rhinomanometric evaluation of the nasal airway resistance was performed in sitting and recumbent positions at rest, and after physical effort in the sitting position. The maxillary sinus was punctured after local anaesthesia through the canine fossa using a specially designed cannula. All test methods (I-III) were then performed both in sitting and recumbent positions. Retests were performed in 5 subjects (10 maxillary sinuses) after an interval of 2 months and the recordings were then also performed with methods II and III after venous congestion with the aid of a neck cuff.

RESULTS

The pressure relationship between the maxillary sinus and the ipsilateral nasal cavity (Method I) was found to be 1:1 in sitting as well as in recumbent positions. For simultaneous pressure recording in the sinus and the contralateral nasal cavity the pressure relationship was < 1 . No time-lag was observed.

Determination of the ostial resistance during inspiration in the sitting position during nasal breathing (Method II) could be performed in 13 sinuses, but in the remaining 22 the ostial

resistance was $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3.\text{s}^{-1}$ at a flow of $2.0 \text{ cm}^3.\text{s}^{-1}$ and could not be measured exactly. The equivalent ostial diameters were estimated from a diagram (paper I) in 12 sinuses, while the remaining 23 ostia were $> 2.5 \text{ mm}$ and thus not measureable with method II. When using a constant artificial air-flow (Method III) the equivalent ostial diameters could be estimated in all sinuses. The mean equivalent ostial diameter was 2.54 mm (S.E. ± 0.13) with a range of $1.13\text{--}4.5 \text{ mm}$. In comparable cases no statistical difference was found between equivalent ostial diameters estimated with methods II and III. The equivalent ostial diameters showed a statistically significant reduction in recumbency (Methods II and III), and also after application of the inflatable neck cuff (Method III). A statistically significant relationship was also observed between the airway resistance of the right or left nasal cavity and the corresponding equivalent ostial diameter in sitting and recumbent positions (Method III), but this relationship disappeared when the equivalent ostial diameters, measured at rest, were correlated to nasal airway resistance after physical effort.

CONCLUSIONS

Method I is of value in judging if the ostium is patent or not. With method II, ostial resistance $\geq 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3.\text{s}^{-1}$, which corresponds to equivalent ostial diameters $\leq 2.5 \text{ mm}$, can be estimated, while equivalent ostial diameters up to 4.7 mm can be measured with method III. No statistically significant difference was found between the results of the equivalent ostial diameters estimated with methods II and III in comparable cases.

III. STUDIES OF THE MAXILLARY OSTIAL FUNCTION IN CASES WITH MAXILLARY PAIN, INTRASINUSAL CYSTS, AND CHRONIC SINUSITIS

This paper compares the ostial function in three groups of patients with that in healthy subjects (paper II) tested with the three different methods described in paper I. The selection of the patients was done in order to obtain one group where an impaired ostial function could be expected (chronic sinusitis). The groups with maxillary pain and intrasinus cysts were selected as no analysis of the ostial function in such cases has previously been described.

RESULTS

No impairment of the ostial function was observed in the groups with maxillary pain and intrasinus cysts (Methods I-III), as compared with values obtained in healthy subjects (paper II).

In the group with chronic sinusitis (6 sinuses) three types of naso-sinus pressure changes were found during nasal breathing (Method I): equal pressures in the ipsilateral nasal cavity and the sinus; lower pressure changes within the sinus than in the nasal cavity of the ipsilateral side, no pressure changes within the sinus.

The results obtained from patients with chronic sinusitis could also be separated into three different types by estimating the ostial resistance and equivalent ostial diameters (Method II). The first type consisted of 2 sinuses with ostial resistances $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ corresponding to equivalent ostial diameters $> 2.5 \text{ mm}$. The second type (1 sinus) showed measurable ostial resistance $> 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ corresponding to an equivalent ostial diameter $< 2.5 \text{ mm}$. In the third type consisting of 3 sinuses no pressure-flow recording was possible during nasal breathing because of a non-patent ostium.

With the application of a constant artificial air-flow into the sinus (Method III), equivalent ostial diameters could be estimated in all cases in the sitting position and in all cases except one in recumbency. In the three sinuses with closed ostia (Methods I and II) all were forced open by the overpressure within the sinus, created by the artificial air-flow. The equivalent

ostial diameters, estimated with method III after the ostia were forced open, were significantly separated from values of healthy subjects (paper II).

CONCLUSIONS

The ostium can be judged as patent, non-patent or partially obstructed with naso-sinusal pressure recording, but no further grading of the ostial function is possible. With the pressure-flow recording the ostial function can be evaluated under physiological conditions when the ostium is patent, while the use of a constant artificial air-flow permits estimation of the equivalent ostial diameters even in physiologically non-patent ostia. However, the latter values do not reflect the true functional state of the ostia as these have to be forced open by the constant air-flow applied to the sinus.

IV. NEW ULTRASONIC EQUIPMENT FOR DIAGNOSTIC SCREENING OF PARANASAL SINUSES - AN EXPERIMENTAL STUDY

There is little commercially available equipment satisfying the needs for screening of paranasal sinuses with suspected sinusitis. This paper describes three different pieces of ultrasonic equipment adapted for screening purposes and tested in experiments on plexiglass- and bone sinus models as well as in human sinuses.

EQUIPMENT

Generally, an ultrasonic apparatus consists of a transmitter, a receiver and a display unit. In the present study three different display units - oscilloscope (OSC), light emitting diodes (LED), and gas discharge (GD) display - have been tested and evaluated. A newly designed receiver with a quasi-logarithmic amplifier was used in all display units. The properties of this device are such that weaker signals are amplified more than stronger ones, thus allowing echoes with widely varying intensities to be simultaneously displayed. This means that the equipment gives an improved display and is easier to handle than other available apparatus.

RESULTS

Air was separated from other types of content in the sinus models and penetration of up to 16 mm bone was recorded on all display units. Artificial mucosal swelling (≤ 3 mm), fluid and cyst-like objects were separated from each other with the OSC-display. Artificial mucosal swelling < 8 mm could not be detected with the LED- and GD-displays, and these two display units could not differentiate between saline solution or cyst-like objects. A statistically significant difference was found in the amount of saline solution detectable in a human sinus with the OSC (mean 1.6 ml, range 1-3 ml) compared with the GD-display (mean 2.1 ml, range 1-5 ml), and the LED-display (mean 3.1 ml, range 1-5 ml). Artificial cysts in human sinuses were detected with the OSC-display but not with the other display units.

CONCLUSIONS

Of the three different display units tested, the OSC-display seems to be best suited for clinical and scientific purposes, while the LED- and GD-displays may be useful for screening purposes.

V. A COMPARISON BETWEEN DIFFERENT ULTRASONIC DISPLAY TECHNIQUES, RADIOGRAPHY AND INVASIVE CONTROL FOR DIFFERENT DISORDERS OF THE PARANASAL SINUSES

The three ultrasonic display units - oscilloscope (OSC), light emitting diodes (LED), and gas discharge (GD) display - described in paper IV have been tested in a clinical material consisting of 100 patients (138 maxillary sinuses and 10 frontal sinuses). The results of the ultrasonic examination were compared with those of radiography and also checked invasively by sinus lavage, sinoscopy, antrostomy or frontal sinus trepanation.

RESULTS

With the OSC-display, 97 % of the sinuses were correctly judged as normal or pathological. The corresponding figures for the LED- and GD-displays were 90 % and 93 %, respectively. The screening capacity of the radiological examination in separating a diseased sinus from a healthy one was 95 %. Thus, no statistically significant difference was found in the screening capacity of the different display units and the radiological examination.

When separating different pathological conditions, the OSC-display was significantly more efficient than the LED- and GD-displays. Secretion was correctly diagnosed with the OSC-display in 26/34 sinuses compared with 11/34 with the radiological examination performed in three standard projections. Cysts were correctly indicated in 25/35 sinuses with the OSC-display and in 23/35 sinuses with the radiological examination. In cases with total opacity with the radiological examination the sinus content was correctly diagnosed in 19/23 cases by using the OSC-display. The corresponding figure for both the LED- and GD-displays was 15/23. In cases with frontal sinusitis agreement was found in 90 % of the cases between the different display units and radiography, as confirmed by trepanation.

CONCLUSIONS

The three different display units have a screening capacity comparable to radiological sinusal examination. The OSC-display is statistically significantly better than the other display units and radiography in separating different pathological conditions within the sinusal cavities.

GENERAL DISCUSSION

MAXILLARY FUNCTION TESTS

In a healthy condition a paranasal sinus is connected via its ostium to the atmosphere and can be looked upon as an "open-ventilated gas pocket" according to Rahn & Liew (1955). In this respect the sinus is comparable to a pulmonary alveol but not to the middle ear cleft which is an "open non-ventilated gas pocket". For more than 100 years many attempts have been made in order to explain the functional role of the paranasal sinuses but no plausible theory exists so far. However, it is a generally accepted fact that a properly ventilated sinus is a pre-requisite for the maintenance of sinusal health. A mucosal swelling caused by an upper respiratory tract infection may reduce or close the maxillary ostium which is of great pathophysiological importance in the etiology of paranasal sinusal infections. Therefore, much interest has been directed towards the functional state of the maxillary ostium, and many, more or less physiological test methods have been used to evaluate its function both in healthy and diseased status.

Direct measurements of the airway resistance during nasal breathing seem to be a method which fulfils most of the criteria for a physiological test of an ostium. Such a method was described by Andréasson et al. (1977) and used when testing the function of the naso-frontal duct in trephined frontal sinuses. With the use of a specially constructed cannula inserted through the canine fossa this technique was easily adapted for testing the maxillary ostium. In the present study simultaneous pressure recording in the sinus and the ipsilateral nasal cavity was also performed during nasal breathing as this method is hitherto the one most used. The third method used was determination of the "functional size of the maxillary ostium" with a constant artificial air-flow into the sinus (Aust & Drettner, 1974b). This method expresses the ostial resistance during sinusal overpressure.

Two of the most common ways of expressing ostial function are either as ostial patency or ostial resistance and the use of these expressions has until now been confusing. Patency in the common sense means accessibility to the sinus, while ostial resistance

must be restricted to a quotient of simultaneously recorded pressure differences and defined air- or fluid-flows. Flottes et al. (1960) and Mann (1977), when testing the "ostial resistance", expressed the passive forcing pressure for air in mm H₂O and Drettner (1965b), Zippel & Meier (1968) and Rantanen (1974) expressed the passive forcing pressure for saline solution in cm H₂O. On the other hand, Aust & Drettner (1974b) measured the ostial resistance during unphysiological air-flow levels (1-6 litres per minute) applied into the sinus and expressed their results as the "functional size" in ostial diameter or square area. This procedure is valid for the passive ostial resistance in the sinu-nasal direction only. Zippel et al. (1974) used the same procedure as mentioned but instead of air they used saline solution. This is not a physiological test as the sinuses normally contain air and it is well known from studies on the Eustachian tube that saline solution lowers the surface tension considerably (Flisberg et al., 1963).

The pressure-flow method permits an isolated determination of the ostial resistance in naso-sinusal as well as in sinu-nasal direction and is only dependent on the diameter of the ostium (paper I). In the case of high air-flow levels, small diameters and large sinusal volumes a slight hysteresis may occur (paper I), but this does not affect the results. With the use of a log-log diagram the differential pressure across the ostium at a known air-flow can be transformed into the equivalent ostial diameter which permits direct comparisons with the method using a constant artificial air-flow (paper I). In order to obtain measurable pressure differences across the ostium (> 0.05 mm H₂O) an ostial air-flow rate of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ was necessary which required a moderate forcing of breathing (papers II and III). This air-flow level is easily reached as the sinus is open to the atmosphere via the cannula of puncture and the flow meter. In a closed sinus only open to the atmosphere through its ostium the ostial flow levels are lower. The calculated mean ostial air exchange volume of 0.02 cm^3 per breath (Svanholm et al., 1981) does not permit airway resistance measurements by any method known by us. The pressure-flow method permits an accurate determination of ostial resistances $\geq 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ corresponding to equivalent ostial diameters $\leq 2.5 \text{ mm}$, while resistance values smaller than

those mentioned and corresponding larger diameters cannot be measured. This limitation, however, is of minor importance as Aust & Drettner (1974a) found that the oxygen content of the sinus was related to the ostial size up to a diameter of 2.5 mm. Sinuses with ostia > 2.5 mm showed a constant oxygen content independent of the ostial size. They also found that many patients with ostial diameters < 2.5 mm complained of symptoms reminiscent of sinusitis (Aust et al., 1977). On the other hand, many healthy individuals without previous history of sinusitis showed ostial diameters < 2.5 mm (paper II), which was also observed by Aust & Drettner (1974b). A possible explanation of the maintenance of sinusal health in these cases might be that the pulse volume changes of the sinus mucosa in cases with narrow ostia exceed the "dead space" of the ostia, thereby taking part in the ventilation of the sinus (Svanholm et al., 1981).

With simultaneous pressure recording in the nose-sinus model (paper I) the critical ostial diameter for a time-lag, seen as a hysteresis, in the recordings was ≤ 0.6 mm. The time-lag was dependent on ostial diameters, sinusal volumes and air-flow rates. In cases with patent ostia the pressure relationship was invariably 1:1 provided that the pressure recording was performed in the ipsilateral nasal cavity (papers I-III). The relationship between simultaneously recorded sinusal and contralateral nasal cavity pressures was < 1. These findings are due to the pressure contribution of the posterior part of the nasal cavity (Fischer, 1969) and this may be more pronounced in the case of a narrow posterior nasal fossa, e.g. a septal deviation. Consecutive measurements, as suggested by Kortekangas & Rantanen (1976), seem erroneous as it is impossible for the subject to breathe in exactly the same manner during sinusal and contralateral nasal recordings.

When a constant artificial air-flow was applied into the sinus the pressure rise was independent of the sinusal volume (paper I), and thus, the ostial resistance could be calculated in all measurable cases. The only limitation of the method is in ostia exceeding 5.6 mm in diameter at an air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$. As suggested by Flottes et al. (1960) intrasinusal pressures exceeding 200 mm H_2O were not allowed in order to avoid any risk of air embolism. In only one case (BE sin) the intrasinusal

pressure rise exceeded this value (paper III), and therefore the artificial air-flow had to be cut off.

When comparing the simultaneous naso-sinusal pressure and the pressure air-flow methods there is good agreement except for one case (LB) (paper III). The largely good agreement is probably due to the fact that both methods are used under the same physiological conditions, i.e. nasal breathing. On the other hand, the pressure-flow method permits a quantitative grading of the ostial function not possible with the simultaneous pressure method. In the case of LB some degree of quantification was given by the latter method as the pressure relationship was < 1 with a large hysteresis. However, this observation must be questioned as both the pressure air-flow and the constant air-flow methods indicated a non-patent ostium in this case (Table III, Fig. 2 D, paper III). A possible explanation for the pressure transmission recorded might be that breathing changes are transmitted via a heavily congested mucosa into a sinus with a small volume.

In 6 of the sinuses with chronic sinusitis 3 were patent although only one was measurable with the pressure-flow method in the recumbent position during nasal breathing. When tested with the constant artificial air-flow method all were measurable except one in the recumbent position (Table III, paper III). Thus, the latter method does not mirror the true functional state of the ostium as some of the ostia in sinuses with chronic sinusitis have to be forced open (Fig. 2, paper III).

In the three patent ostia (Table III, paper III) the ostial diameters were invariably larger when measured with the pressure-flow method compared with the constant artificial air-flow method. A plausible explanation for this phenomenon might be the sucking (Bernouille effect) on the mucosa by the high air-flow level used ($16.7 \text{ cm}^3 \cdot \text{s}^{-1}$). Similar effects on narrow passages in the nose have been reported by Proetz (1932) and further evaluated by Gray (1967) who stated that "it is the rate of the air-flow over a certain point and not the direction which is important". However, in healthy individuals (paper II) as well as in comparable cases with intrasinusal cysts and maxillary pain (paper III) the ostial diameters measured with the pressure-flow method were never larger than when measured with the artificial air-flow method. This might indicate that the mucosal lining of the ostia is not as

affected in the groups with maxillary pain and intrasinusal cysts as the ostial mucosa in chronic sinusitis.

Nasal pressure changes, created with Toynbee's manoeuvre and the sniff-test, were propagated to the maxillary sinus but without residual negative pressures. Drettner (1965a), however, found that the ostium sometimes acts as a one-way valve in case of infected sinuses. This valve phenomenon, mostly acting in the sinu-nasal direction, brings about a high negative intrasinusal pressure. Ingelstedt (personal communication, 1979) suggested this as a possible explanation in the development of an intrasinusal cyst by a release of the mucosal lining from the periost. Tissue fluid might then accumulate between the mucosal lining and the periost thereby resulting in an "intrasinusal cyst". Studies to evaluate this theory are in progress. The sniffing habits in children, especially during an upper respiratory tract infection, are well known and their effects on the middle ear have been evaluated by Gray (1967). A possible explanation for totally obliterated sinuses in children's "sinusitis" might be the one-way valve phenomenon where the negative intrasinusal pressure might cause a non-infectious oedema.

The postural effects of the nasal and tubal functions are well known (Rundcrantz, 1969a,b). With the pressure-flow method and the constant artificial air-flow method a significant reduction of the ostial diameter was found in recumbency as compared with the sitting position (papers II and III). This is due to increased venous congestion and is confirmed by the use of an inflatable neck cuff (paper II). The mean reduction of equivalent ostial diameter in mm (paper II) is about 9 %. If the equivalent ostial diameter is transformed into an area, assuming that the ostium is circular, the mean reduction is about 18 %. The decrease in area, due to position, is as high as 47 % in diseased cases (Table III, paper III). A close relation between nasal resistance at rest, both in the sitting and the recumbent positions, and the ostial diameters, estimated with the constant artificial air-flow method, was found in healthy individuals (paper II). This relationship disappeared when the nasal resistance was measured after physical effort and compared with the ostial diameter at rest. Among the cases with chronic sinusitis (paper III) two cases showed pathological rhinomanometri values of the nasal

resistance at rest. These cases also showed the highest ostial resistance values in recumbency. This underlines the importance of decongesting nose drops in rhinitis as well as in sinusitis and also the importance of the body position during the treatment of an upper respiratory tract infection (Rundcrantz (1969a,b)).

In order to obtain correct results when using the pressure recording and the pressure air-flow methods a specially designed cannula had to be constructed (paper I). It is of utmost importance that the tip of the cannula of measurement is located outside the cannula of punction otherwise the pressure results will be totally misleading, especially upon the application of high air-flow levels with the constant artificial air-flow method. As can be seen in Fig. 2 (paper I) the cannula of measurement is at least 10 mm outside the tip of the cannula of punction. In order to avoid direct contact between the mucosa and the measuring device the position of the cannula within the sinus was checked with an ultra-thin fiberscope. As both the naso-sinusal pressure and the pressure-flow methods are used during dynamic conditions, a frequency balance test of the transducer systems before and after every test is necessary. On the other hand, the constant air-flow method registers pressure during static conditions and is thus not dependent on frequency balance between pressure-flow recordings. The naso-sinusal pressure method was always used initially and was of value for controlling the air-tightness between the equipment and the patient as a reduction of the pressure relationship was invariably found in case of a leakage when recording between the sinus and the ipsilateral nasal cavity.

Of the three methods described in papers I-III the simultaneous pressure recording technique does not give any information in addition to the pressure-flow method. Both are used during dynamic nasal breathing and showed good agreement in judging if an ostium is patent or not. The pressure-flow method, however, quantifies the function of ostia of critical sizes, which is of clinical importance and there is no risk for air embolism with the use of this method as the driving pressure is the patient's own nasal breathing. In this respect the constant artificial air-flow method is not completely harmless. The present procedure, which encompasses all methods described, is technically advanced and well fitted for research work such as evaluation of pharmacological

effects on the ostial function, both in health and disease. Thus, rhinomanometry gives information about the nasal influence on the ostial function and the pressure-flow method information about the physiological ostial function. The combination with the artificial air-flow method enables distinction to be made between ostial obstruction caused by skeletal stenosis and mucosal swelling.

A simplified device using the pressure-flow method only with an oscilloscope as the recording unit has been used for evaluation of the naso-frontal duct in our clinic (Andréasson et al., 1982). This procedure has also been applied to maxillary ostial function testing. It is mainly used for evaluating patients subjected to different kinds of maxillary surgery. A study of a series of patients with acute maxillary sinusitis has been started in order to investigate the role of ostial function impairment in the pathogenesis of chronic sinusitis.

ULTRASONOGRAPHY

The symptoms and signs of sinusitis resemble very much those of other infections in the upper respiratory tract (Axelsson & Runze, 1976). As the therapy differs considerably between, e.g. acute sinusitis with secretion and common rhinitis, there is need for a diagnostic method which securely differentiates between these conditions. Radiography using four standard projections was only successful in 24 % of the cases in detecting secretion when checked against invasive examinations (Axelsson et al., 1970), thus alternative diagnostic procedures are needed.

An ideal piece of diagnostic equipment must be adaptable to all categories of patients and without any risk to patients or investigators. The method must also be reliable, time-saving and inexpensive.

Ultrasonic examination which has a growing clinical importance in different medical fields such as cardiology (Hertz & Edler, 1956), obstetrics (Sundén, 1964) and neurology (Leksell, 1955) seems to be a method which fulfils most needs mentioned above and can be adapted for diagnostic investigation of the paranasal sinuses.

Several attempts have been made to use ultrasonography for this purpose, but the pieces of equipment used have been technically complicated with several manual adjustment required. Because of this, the results obtained on different occasions and by different investigators differ considerably. Thus, a simplified but still reliable piece of equipment was needed.

When constructing the present pieces of equipment the following demands were taken into consideration, namely simplicity, reliability, documentation possibility, mobility and low cost.

Three different ultrasonographic systems were constructed using oscilloscope (OSC), light emitting diodes (LED) and gas discharge (GD) displays as the recording units, all with a quasi-logarithmic amplifier as the basic unit (Holmer & Lindström, 1978). With this technically advanced amplification system the equipment is easy to handle as the external manual controls of the amplifier can be excluded and results obtained from examinations on different occasions and by different investigators may

be relied upon. The need for documentation was solved in the OSC- and GD-display systems by using an internal memory, so that the display unit can be "frozen" for careful examination of the echoes or documentation with a Polaroid camera. In order to get a piece of equipment easily transportable, modern electronic components were used, which also ensure that the equipment is inexpensive to produce.

A single prominent echo from the back wall of the sinus (BWE) has been reported by several authors as a sign of secretion in the sinus (Kitamura & Kaneko, 1965; Gilbricht & Heidelbach, 1968; Mann, 1975; Jannert, 1980; Revonta, 1980). In healthy sinuses an amount of 1-3 ml (mean 1.6 ml) of saline solution was necessary so that the back wall echo (BWE) could be detected when using the OSC-display (paper IV). Similar results were also obtained with the other display systems and this is in accordance with the findings in cases with slight mucosal swelling (Revonta, 1980). On the other hand, Axelsson et al. (1970) found that the amount of secretion within a sinus must be at least 5 ml to be detectable when using five standard radiographic projections. This speaks in favour of ultrasonography as a routine for suspected sinusitis to confirm or to exclude the presence of secretion within the sinus. However, the anatomical details cannot be analysed but in the majority of cases with paranasal sinus infection there is no need for a detailed mapping of the anatomy. Thus, routinely performed radiological examinations of the paranasal sinuses can be excluded in most cases of suspected acute sinusitis. Thereby, the amount of unnecessary radiological exposures to the lens of the eye can be reduced.

Mucosal swelling < 3 mm is not detectable when using the OSC-display system and mucosal swelling < 8 mm could not be detected with the other two display systems (paper IV). However, the clinical value of information on minor mucosal swelling might be questioned (Jannert et al., 1981c).

A double echo (DE), interpreted as a sign of an intrasinus cyst, was first reported by Kitamura et al. (1969). They supposed that the double echo was generated by one reflection in the back wall of the cyst and the second from a reflection of the ultrasound beam from the back wall of the sinus. This explanation provides at least a small amount of secretion between the cyst

and the back wall of the sinus which is plausible, as shown in model experiments (paper IV). However, double echoes were also observed in cases with intrasinus cysts without any detectable secretion between the cyst and the back wall of the sinus (paper IV). In these cases the double echo is explained by multiple reflections inside the cyst, as illustrated in model experiments (paper IV). The double echo seems to be a reliable sign of an intrasinus cyst as there was no statistically significant difference in the number of detected cysts when using the OSC-display and radiological examination compared with invasive control (paper V).

In sinuses, shown to be totally opaque by radiological examination, ultrasonic examination using the OSC-display system correctly predicted the intrasinus contents in most cases (paper V).

It thus seems that radiological examination of the paranasal sinuses in most cases can be replaced by an ultrasonographic examination using an oscilloscope as the display unit. The method is non-invasive and harmless to patients as well as investigators with the frequencies used. The OSC-display gives more information than the other two display systems (paper V). The GD-display and LED-displays seem to be most suited for screening purposes (paper V). The GD-display is better in some respects, e.g. it is easier to find the echoes with the GD-display and it is also easier to study and to document the echoes using the memory and the "freezing" possibilities. The GD-display can be used in full day-light, which is not possible with the LED-display.

The errors when using ultrasound for diagnostic purposes have been discussed by Mann (1977) and Revonta (1980). Some important errors must, however, be stressed. Different anatomical structures such as tooth roots or the zygomatic arch give false positive echoes. False negative results can appear if the amount of secretion is small (< 3 ml) (paper IV) and if the secretion within the sinus is mixed with air bubbles, as seen in two sinuses (paper V). The latter error has not earlier been reported in the literature, as far as we know.

In order to use the ultrasonic equipment properly the investigator must have at least some knowledge of the basic principles

of ultrasound. There is also a need for a training program preferably together with an experienced investigator to learn how to evaluate the different types of echograms and how to avoid different sources of error. It is important that the equipment is periodically checked in order to detect technical faults and this can be carried out using a phantom which simulates human tissue. Such a device is being tested in our clinic.

The OSC-display system (Sinuson 810^{*}) has been used in the clinical routine at the ENT-department, Malmö General Hospital, for the last year and more than 1 500 ultrasonic examinations have been performed. The need for repeated radiological examinations of the paranasal sinuses has been correspondingly reduced as the ultrasonic display system is also used for healing control. Since the ultrasonic examinations began the frequency of sinusal lavages has increased considerably. A more active treatment of acute sinusitis is also supported by Engquist et al. (1981) who reported that repeated sinusal lavages, several times per day, reduced the healing period of acute sinusitis. This is in accordance with the experimental studies presented by Reimer et al. (1981) regarding oxygen and carbon dioxide pressures and mucociliary activity in non-ventilated maxillary sinuses.

Disadvantages with the pulse echo method. The A-mode method gives no information about the bone anatomy or signs of osteitis or malignancy. Mucosal swelling of a minor degree cannot be detected with ultrasonography, but the clinical importance of minor mucosal swelling must be questioned.

Advantages with the pulse echo method. The method, which is non-invasive, can be used on all patients, including children and pregnant women, and also after previous radical surgery of the sinuses. The ultrasound examination takes less than 10 minutes and can be repeated whenever necessary. The method is harmless with the transmission effect used ($< 10 \text{ mW/cm}^2$). Secretion, cysts and mucosal swelling can generally be diagnosed and separated from an

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air-filled sinus when using the OSC-display system. The ultrasound method with A-mode data presentation eliminates diagnostic antral lavage, which is of some inconvenience to the patient. The pulse echo method is also of value in confirming secretion within the frontal sinuses. In this respect a combination of ultrasonic and radiologic examinations is recommended for an accurate diagnosis in these cases.

SUMMARY

Three different maxillary ostial function tests (simultaneous pressure recording in nose and sinus; simultaneous pressure and air-flow recording between nose and sinus; recording of the intra-sinusal pressure rise with a constant artificial air-flow into the sinus) and three different ultrasonic display systems (oscilloscope; light emitting diodes; and gas discharge display) were tested in model experiments, evaluated on a series of healthy subjects and applied to clinical material. The following conclusions could be drawn:

- No quantitative evaluation of the ostial function was possible when using the simultaneous naso-sinusal pressure recording method.
- The ostial function can be expressed as ostial resistance or in the corresponding equivalent ostial diameter with the pressure air-flow method and the constant artificial air-flow method. An isolated determination of the critical ostial function in both the sinu-nasal direction and the naso-sinusal direction during nasal breathing was only possible with the simultaneous pressure-flow method. With the constant artificial air-flow method the ostial resistance could only be estimated in the sinu-nasal direction. Due to the two different air-flow levels used, the values of the ostial resistance, obtained with the pressure-flow method and the constant artificial air-flow method, are only comparable to each other when transformed into equivalent ostial diameters.
- In cases with impaired ostial function, estimated with the pressure-flow method, the constant artificial method does not mirror the true functional state due to the non-physiological air-flow level used.
- No impaired ostial function was found in cases with maxillary pain and intrasinusal cysts, but in cases with chronic sinusitis the ostial function was considerably deteriorated compared with normal subjects.
- When testing the three different ultrasonic display systems in model experiments, air could be separated from other types of sinusal contents with all the display systems. Artificial cysts

could be detected with the oscilloscope display but not with the other display units. The amount of saline solution needed to be detected with all the display units was 1-5 ml in normal sinuses, but the OSC-display was statistically significantly more efficient than the other display units in this respect.

- The three display units showed the same screening capacity as a radiological examination in separating healthy sinuses from diseased ones.
- The oscilloscope display system was significantly more efficient than radiography in detecting secretion but no difference was found in the capacity to predict intrasinusal cysts. With the oscilloscope display the intrasinusal content could be correctly judged in most cases where radiography showed total opacity.

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PATENCY TESTS OF THE MAXILLARY OSTIUM - MODEL EXPERIMENTS

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Abstract. The function of the maxillary ostia (diameters 0.22-4.7 mm) has been evaluated in experiments on a nose-sinus model with variable sinusal volumes. A piston-pump producing to and fro volumes of 467 cm³ of air per revolution was used at a speed of 10 and 20 revolutions per minute (rpm). Three different techniques were used: simultaneous pressure recording in the sinus and the nose (Method I); simultaneous recording of the differential pressure between nose and sinus and the air-flow through the ostium (Method II); recording of the pressure rise inside the sinus upon the application of a constant artificial air-flow of 16.7 cm³.s⁻¹ or 2.0 cm³.s⁻¹ (Method III). All variables were recorded on an ink jet recorder and onto tape when using methods I and II for later analysis on an x-y recorder. A pressure relationship of 1:1 was found between nose and sinus independently of ostial diameters, sinusal volumes and piston-pump rates. The first method did not permit an isolated determination of the ostial function as the pressure values recorded are affected by ostial diameters, sinusal volumes and piston-pump rates. The pressure-flow relationship recorded with the second method was found to be dependent only on the ostial diameters. Hysteresis was observed at ostial diameters < 1.63 mm. This is due to ostial diameter, sinusal volume and the rate of the nasal pressure changes. This method is suitable for an isolated determination of the ostial resistance, from which the equivalent ostial diameter can be calculated. With the third method using static air-flows and pressures the results are independent of the sinusal volume. This method is suitable for estimation of the ostial airway resistance and the equivalent ostial diameter. A striking similarity was observed between the results obtained with the last two methods in estimating equivalent ostial diameters.

The ventilation of the paranasal sinuses is of great importance for their function in health and disease. Different tests have been used experimentally as well as in clinical studies in order to judge patency of the maxillary ostium. Already in 1877 Braune & Clasen studied the pressure variations with a water manometer within the sinus on autopsy specimens. Simultaneous recording of the ipsilateral nasal pressure changes was added to this method by Proetz (1932). He found identical pressure changes within the nose and sinus on a glass and india-rubber model as long as the ostium was adequately open but a time-lag in the pressure peaks was observed when the ostium was gradually narrowed. Experiments were also performed by Drettner (1965) on models similar to that used by Proetz. In further model experiments Rantanen (1974) compared the pressure changes within the maxillary sinus with those obtained in the contralateral cavity of the nose.

Another method for determination of the "functional size" of the maxillary ostium has been described by Aust & Drettner (1974). Into a sinus model with known variable ostial diameters different artificial air-flows of 1-6 litres per minute were introduced through a trocar and the pressure increase created was recorded. A relationship between pressure rise and ostial diameter was found in the model experiments and from these results the ostial diameters in human subjects were estimated by measuring the pressure rise when an artificial constant air-flow was introduced into the sinus. The performance of this method does not mirror physiological conditions in the sense that a one-way air-flow is used instead of nasal breathing.

A direct expression for the airway resistance of the naso-frontal duct during nasal breathing was described by Andréasson et al. (1977) using a simultaneous recording of the pressure difference between the nasal cavity and frontal sinus together with the air-flow through the duct. The resistance was expressed as the ratio between the pressure difference and the flow in $\text{cm}^3 \text{H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$.

All three principal methods, which have been described above, might be more or less suitable for qualitative measurements of the functional state of the maxillary ostium; viz. simultaneous measurements of pressure changes in nose and sinus during nasal breathing (Method I); calculation of the airway resistance in the

maxillary ostium during nasal breathing (Method II); and measurements of the pressure difference between nose and sinus on the application of a constant air-flow into the sinus when no breathing is permitted (Method III).

A nose-sinus model was constructed, in which the simulated maxillary ostium could be changeable.

The aims of the present study have been:

- to construct a cannula of measurement with catheters of suitable lengths and diameters for correct and reproducible air-flow and pressure measurements;
- to compare the three methods using one single piece of equipment adapted for pressure-flow studies;
- to test if the ostial diameter can be estimated as an isolated parameter with any of the three methods and to study the influence of varying sinusal volume and air-flow rates; and
- to compare the equivalent ostial diameters obtained with methods II and III.

METHODS

Nose-sinus model

All experiments were performed on a model of the maxillary sinus and nose (Fig. 1) with a pressure-flow characteristic comparable to that of the human nose (Broms, 1980) (Fig. 1 A). In the model the pressure-flow characteristic of the human nose was obtained by testing different adapters with a well defined bore hole, simulating the nostril. Pressure-flow curves corresponding to the human nose (Broms, 1980) were obtained when the bore hole in the adapter was 4 mm in diameters. The nasal component was connected via exchangeable ostia to the sinus part consisting of a syringe which could be adjustable to volumes of 2, 5, 15 and 25 cm³. Twelve different ostial models, all with a length of 6 mm but with various inner diameters, were used. These diameters given by the manufacturer in mm are 4.7, 3.8, 2.7, 1.63, 1.25, 1.05, 0.84, 0.60, 0.53, 0.42, 0.34, 0.22. The three largest were made of polyethylen and the remaining of stainless steel.

The nose-sinus model was connected to a piston-pump producing a volume of 467 cm^3 per revolution. At a rate of 10 and 20 revolutions per minute (rpm), the peak flow per revolution will be $230 \text{ cm}^3 \cdot \text{s}^{-1}$ and $470 \text{ cm}^3 \cdot \text{s}^{-1}$, respectively (Fig. 1 B). This means that the maximal rate of the pressure changes ($\dot{P}_n$) in the closed nasal model at the two flow rates used was 27 and $180 \text{ mm H}_2\text{O} \cdot \text{s}^{-1}$, respectively (Fig. 1 C) corresponding to the range of the rates of the pressure changes within a human nose.

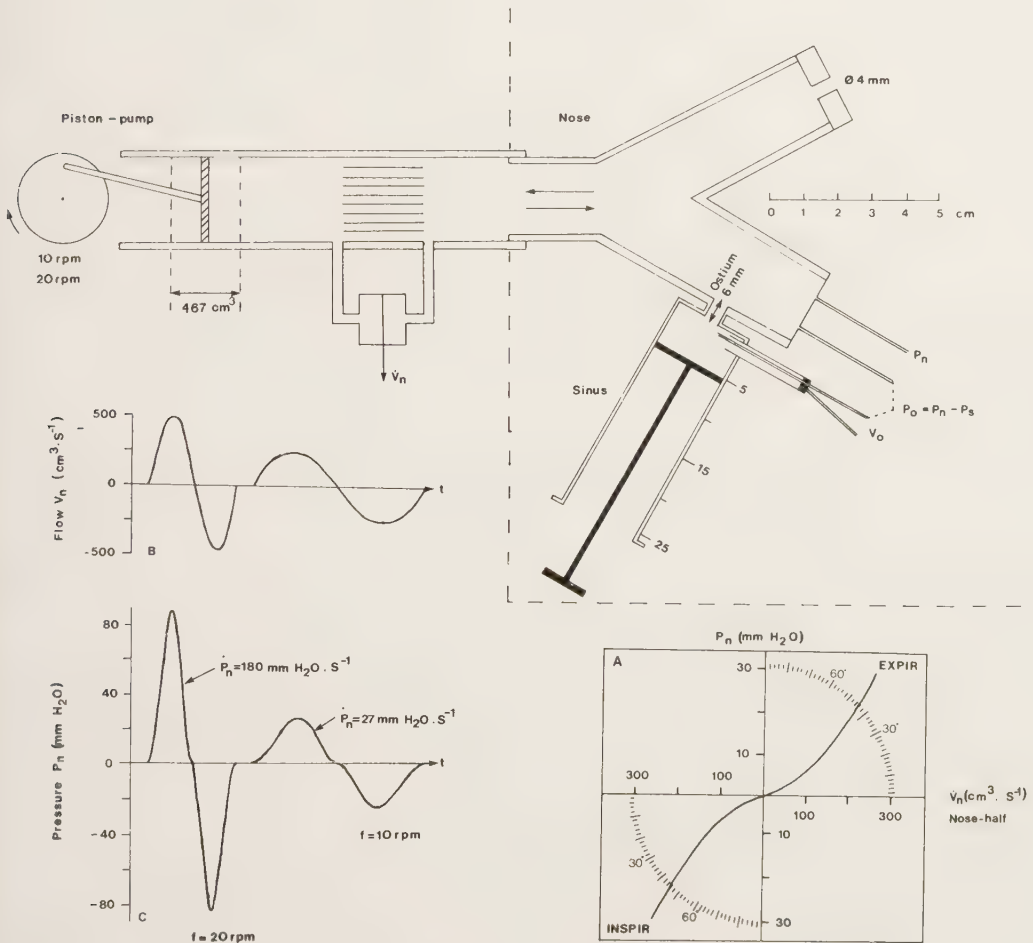


Fig. 1. The nose-sinus model. For explanation, see text.

Cannula equipment

For correct pressure and flow recordings in the sinus a special piece of cannula equipment, useful both for model experiments and clinical examinations, was designed (Fig. 2). The cannula consists of two parts; one for punction and one for measurement, which make an air-tight connection to the sinus model and to each other. The latter consisted of two metal tubes; one with an inner diameter of 0.6 mm and a length of 112 mm, which is used for pressure recording, and one with an inner diameter of 0.9 mm and a length of 20 mm used for air-flow measurements. The short tube can be completely sealed when the model is used for pressure recording.

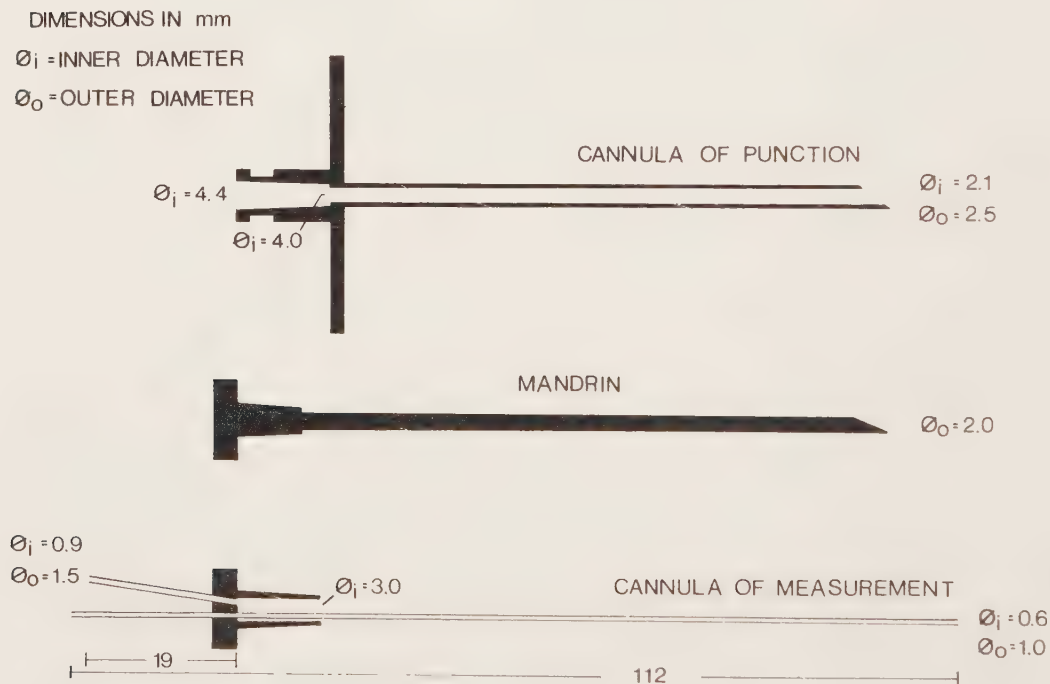


Fig. 2. Cannula equipment.

Pressure recording equipment (method I)

A diagrammatic representation of the equipment is shown in Fig. 3. Two identical pressure transducers are used (Siemens Elema, Sweden, Servoventilator, part No. 63 95 628 E 037), one of which makes an

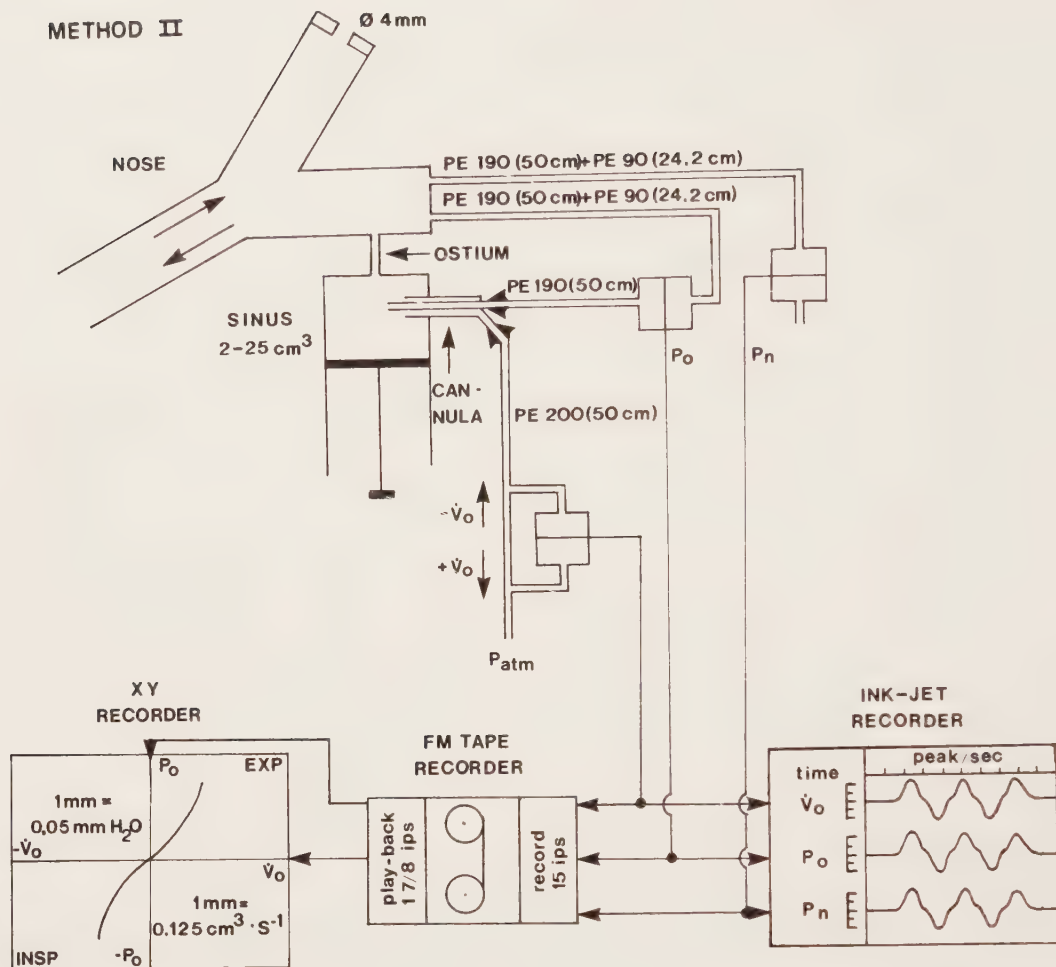


Fig. 4. Differential pressure and air-flow recording equipment (Method II). Pressure in the nose = P_n (mm H₂O). Differential pressure between sinus and ipsilateral nasal cavity = P_o (mm H₂O). Air-flow through the ostium = $\dot{V}_o$ (cm³.s⁻¹).

Differential pressure and air-flow recording equipment (method II)

Figure 4 shows the experimental arrangement used. Two transducers of the same type previously described (Siemens Elema E 037) are used to measure the differential pressure between the sinus and the ipsilateral nasal cavity (P_o) and the nasal pressure (P_n). A flow meter consisting of a resistor and a pressure transducer (E 037) is used to measure the ostial air-flow ($\dot{V}_o$). It is connected to the short tube of the cannula of measurement via a 50.0 cm long PE 200 polyethylene catheter. The ipsilateral opening

of the nose-sinus model is made air-tight using "Leukoflex" tape. The differential pressure is measured using a pressure transducer (E 037) connected to the long tube of the cannula of measurement via a 50.0 cm PE 190 catheter and to the nasal model using a 24.4 cm long PE catheter and a 50 cm long PE 190 catheter. The nasal pressure is measured using a pressure transducer (E 037) connected to the nasal model via a 50 cm long PE 190 and a 24.4 cm long PE 90 catheter. The values of $\dot{V}_O$, P_O and P_n obtained are amplified and recorded on an ink jet plotter and an FM tape recorder as described in method I. Both sides of the differential pressure transducer and the flow meter including catheters and cannula are frequency balanced to have the same phase shifts at nose pressure changes upto $180 \text{ mm H}_2\text{O.s}^{-1}$. After the experiments the differential pressure across the ostium (P_O) versus the flow through the ostium ($\dot{V}_O$) was analysed on an x-y recorder from the tape recorder with a play-back speed of $1 \frac{7}{8}$ ips.

Differential pressure recording equipment with a constant artificial air-flow (method III)

An air-flow of $\dot{V}_O = 16.7 \text{ cm}^3.\text{s}^{-1}$ (1 litre per minute) and $2.0 \text{ cm}^3.\text{s}^{-1}$ for small ostial models (0.22-0.60mm) is blown into the sinus model via the cannula of measurement (Fig. 5). The air-flow is measured by the flow meter and the flow is adjusted by means of a constant flow regulator, which gives a constant flow independent of the ostial resistance. The constant flow regulator working with a high pressure technique (1 atm) is connected to an adjustable microresistor. A valve is used to open or shut off the air-flow. The catheters and equipment used are the same as in method II. The differential pressure across the ostium with a flow of $2.0 \text{ cm}^3.\text{s}^{-1}$ or $16.7 \text{ cm}^3.\text{s}^{-1}$ are recorded on the ink jet recorder.

Calibration

Calibration of P_n , P_s , P_O , $\dot{V}_O$ and frequency balanced control of the equipment were performed before and after each test. Calibration of the pressure was performed with an alcohol manometer and the flow calibration by a programmable microprocessor control

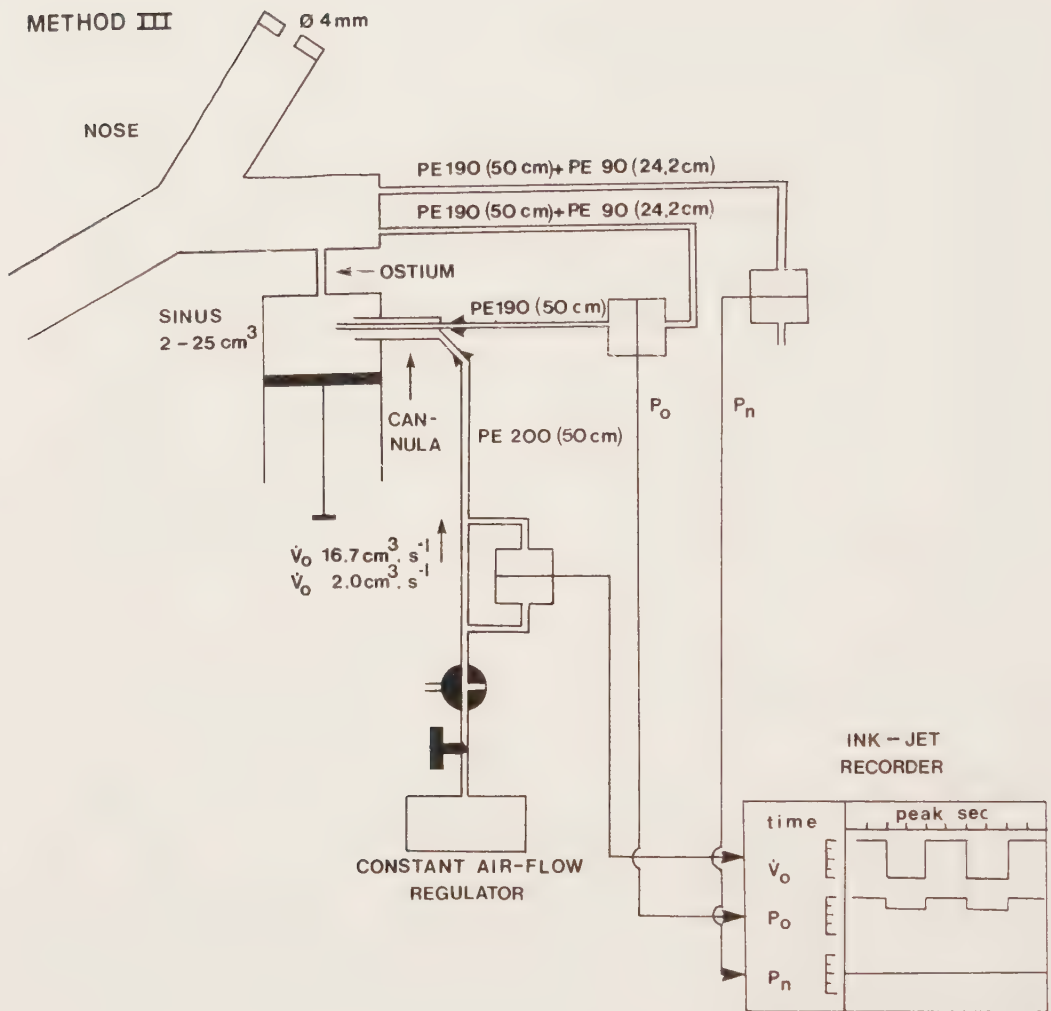


Fig. 5. Differential pressure recording equipment with a constant artificial air-flow of 16.7 cm³.s⁻¹ or 2.0 cm³.s⁻¹ (Method III). Pressure in the nose = P_n (mm H₂O). Differential pressure between sinus and the ipsilateral nasal cavity = P_o (mm H₂O). Air-flow into the sinus = $\dot{V}_o$ (cm³.s⁻¹).

of a Hamilton syringe*. In order to obtain the high degree of frequency balance, which is necessary when recording small pressure differences across the ostium at rapid pressure changes in the nose, the differential pressure transducer including catheters and the cannula for recording of P_o was controlled after each test at the same pressure point on the nose-sinus model.

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RESULTS

Method I

A relationship of 1:1 between the nasal (P_n) and sinusal (P_s) pressures was found with the different ostial diameters, sinusal volumes and air-flow rates. No hysteresis was found until the diameter of the ostium was ≤ 0.6 mm at a sinusal volume of 25 cm^3 and an air-flow rate of 20 rpm (see Fig. 6). When the smallest sinusal volume (2 cm^3) was tested, hysteresis was not observed until the ostial diameter was ≤ 0.34 at the same air-flow rate. At an ostial diameter of ≤ 0.34 mm and 10 rpm hysteresis was only observed at the largest sinusal volume (25 cm^3).

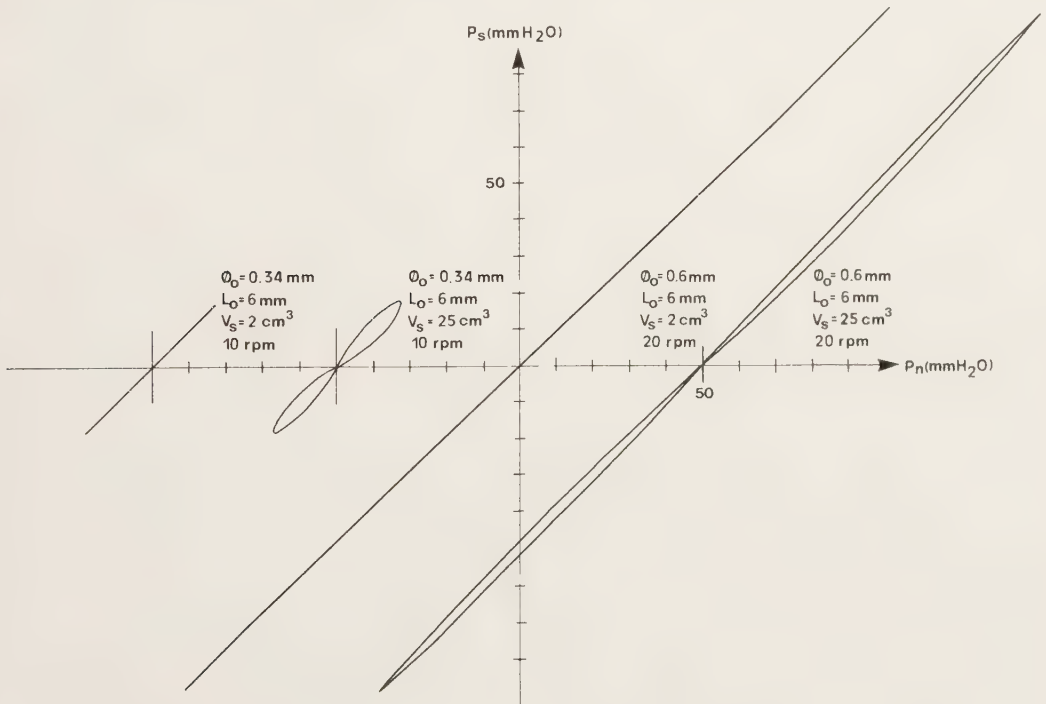


Fig. 6. Examples of critical diameters (ϕ_o), volumes (V_s) and air-flow rates (rpm). Length of the ostium (L_o). (Method I).

Comments: The naso-sinusal pressure method does not permit an isolated determination of the ostial function because the hysteresis is an effect of the ostial diameter as well as of the sinusal volume and the flow rate.

Method II

The pressure-flow curves with different ostial diameters are seen in Fig. 7. The recordings are performed at a flow rate of 10 rpm and a sinusal volume of 2 cm^3 because hysteresis was seen at a flow rate of 20 rpm at sinusal volumes of $\geq 15 \text{ cm}^3$ and ostial diameters of $\leq 1.63 \text{ mm}$. The hysteresis, which is proportional to the velocity of the nasal pressure changes, is explained by a disturbance between pressure and flow recording systems due to a large sinusal volume.

Comments: The pressure-flow relationship is only dependent on the ostial diameters (Fig. 7), while the hysteresis in the pressure-flow curve is also due to the sinusal volumes as well as the rate of the nasal pressure changes. This method therefore permits an isolated determination of the ostial resistance and equivalent ostial diameter.

Method III

A recording with this method is seen in Fig. 5 (below right). The pressure differences obtained were independent of the sinusal volumes. At ostial diameters $\leq 0.6 \text{ mm}$ the sinusal pressure increase at a flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ was too large to be measurable with the equipment used. Therefore, the artificial air-flow was adjusted to $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$, which made the recording of all other ostia except the smallest diameter (0.22 mm) possible.

Comments: Static flows and pressures were used, which did not affect the frequency balance between the recording systems, and therefore the results obtained are independent of the sinusal volumes. This method permits an isolated determination of the ostial size.

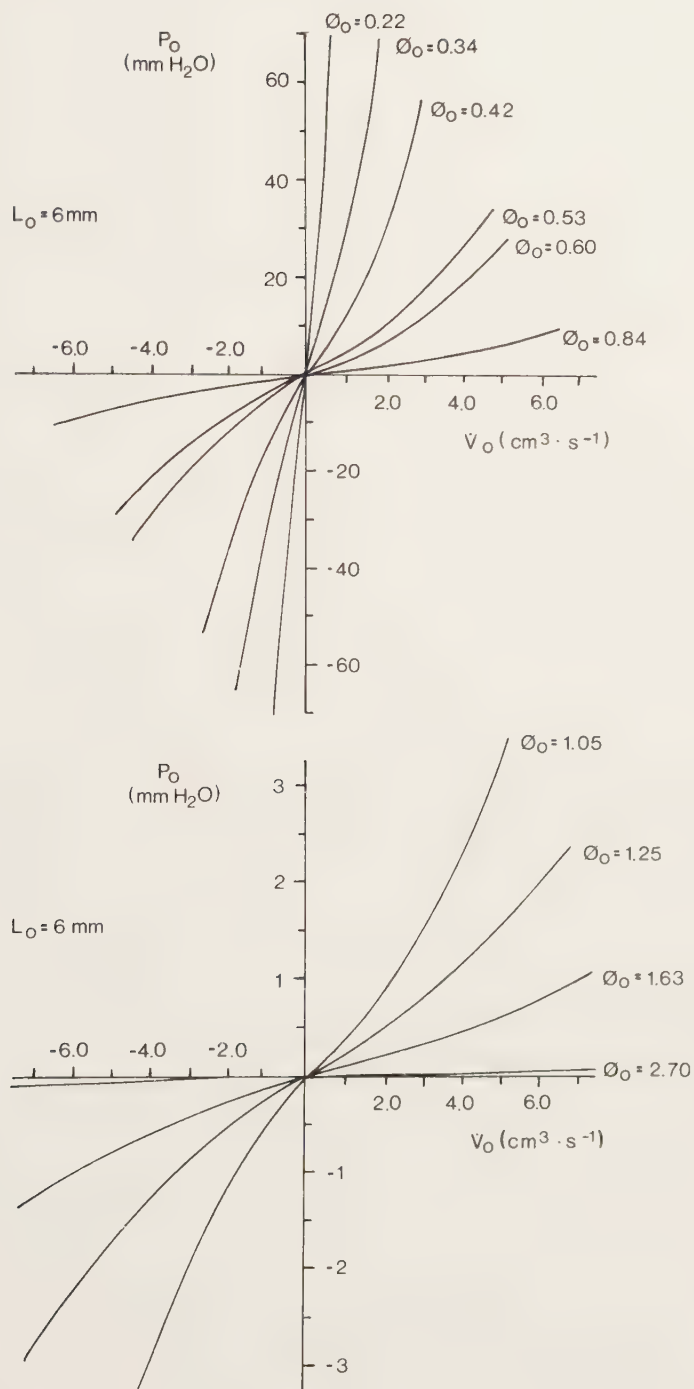


Fig. 7. The pressure-flow curves of the 10 ostia with measurable resistance at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method II).

Calculations

The relation between different ostial diameters and the pressure-difference across the ostium at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Methods II and III) and $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method III) is shown in a log-log diagram (Fig. 8). The relation is exponential with an exponential coefficient equal to 3.7. This is in rather good agreement with Pouiseuille's law which states:

$$P_o = \frac{128 L_o \dot{V}_o (\eta+k)}{\pi \varnothing_o^4}$$

$\dot{V}_o$: air-flow through the ostium
 $\varnothing_o$: diameter of ostium
 P_o : differential pressure
 L_o : length of ostium
 η : viscosity
 k : constant dependent on air density, $\dot{V}_o$, L_o , and shape of the capillary

For a given differential pressure and for a given air-flow the equivalent ostial diameter can be read. For technical reasons these diameters are restricted to 0.34-2.50 mm (Method II) and 0.34-5.6 mm (Method III).

The exponential coefficient of 3.7 calculated from the experiments is not in complete accordance with the theoretically expected coefficient of 4 in the law of Pouiseuille. This might depend on the fact that the air-flow through the ostia is not completely laminar or on the fact that the errors associated with the pressure differences are about 10 %. However, this small difference between the experimental value and the theoretical value is not of great significance when measuring differences in clinical cases.

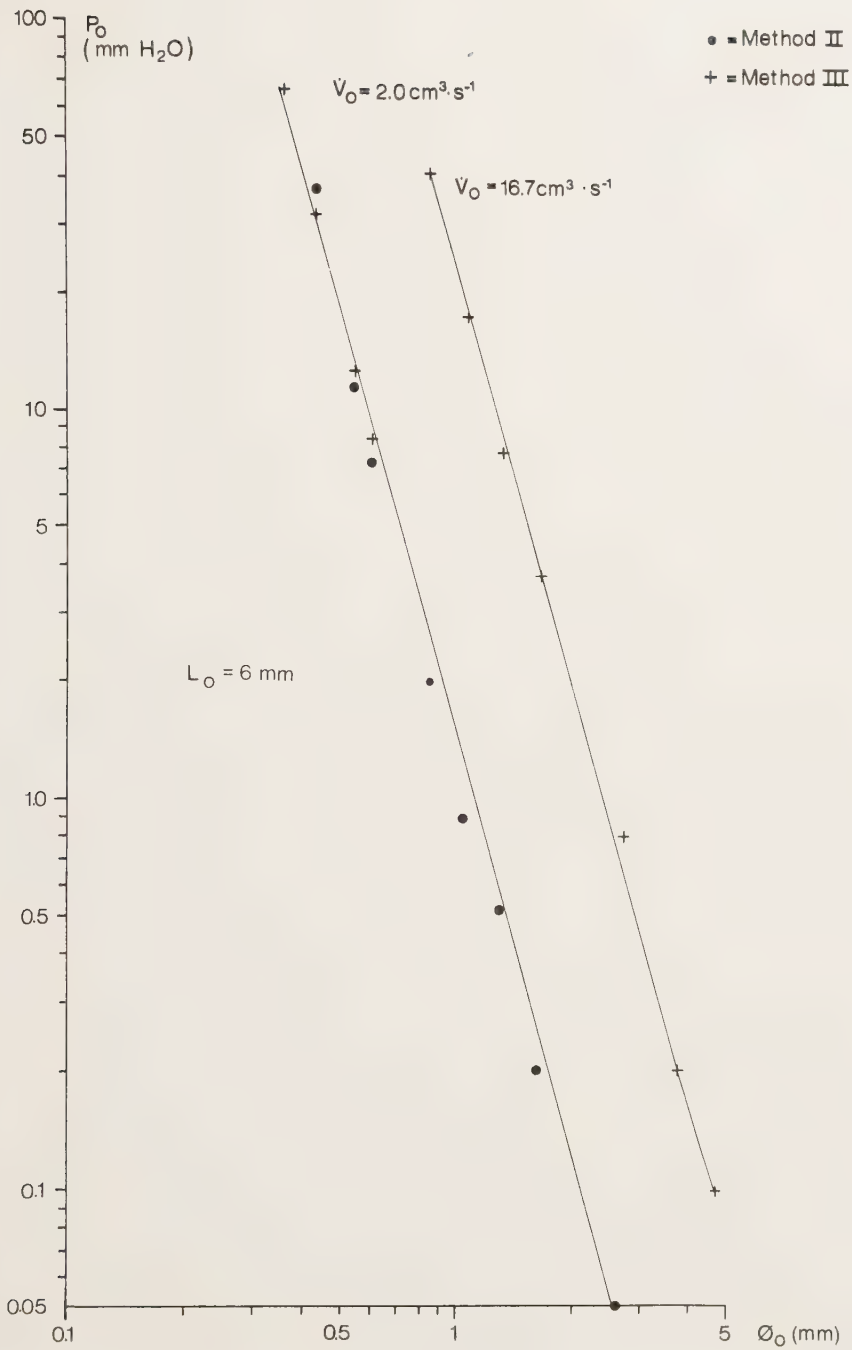


Fig. 8. Diagram for estimation of the ostial diameters from the pressure-flow relationship at $\dot{V}_O = 2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method II) and pressure increase at constant artificial air-flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ or $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method III).

DISCUSSION

When a new test method for naso-sinusal function studies is developed, model experiments in a standardized test situation are necessary in order to evaluate and to compare it with previous methods. However, the model results cannot directly be transformed into a clinical situation as there is no possibility to construct a model which completely mirrors human conditions. For example, there is no equivalent for the mucosal lining in the model and the ostium is circular, while the shape of the ordinary ostium or ostia varies considerably.

In the present study identical nasal and sinusal pressures (Method II) were observed with ostial diameters between 0.22 - 4.7 mm. This is in accordance with the findings of Proetz (1932). On the other hand, Drettner (1965) reported a reduction of the sinusal pressure when the ostium was almost completely closed but no information about the critical ostial size was given. A reduction of the sinusal pressure should indicate a leakage between the interconnection in the equipment used. Method I has been used in clinical experiments as a control of the "air-tightness" in the connection between the cannula and the sinus in order to obtain correct pressure and air-flow volume values with methods II and III (Jannert et al., 1982a). A time-lag as observed by Proetz (1932) and Drettner (1965) was seen on the x-y recorder as a hysteresis in the present study, but the time-lag was not detected on the ink jet recorder due to a lower sensitivity in the pressure/time relationship with this type of recording (velocity of registration 10 mm.s^{-1}). Proetz (1932) noticed an increasing time-lag of the pressure fluctuations of the water manometers at decreasing ostial diameters, while Drettner (1965) observed the time-lag on the ink jet recorder, which was used for pressure recordings in the nose and sinus. The time-lag in the present study observed as a hysteresis is an effect of air-flow rates, as well as sinusal volume and ostial diameter. All three parameters can be analysed with the equipment used. No such information is given before in literature. Simultaneous nasal and sinusal pressure recordings (Method I) thus only give qualitative information of ostial patency, but no isolated grading of the ostial function is possible with this method.

The pressure-flow method (II) described by Andréasson et al. (1977) has not earlier been evaluated in model experiments. The present studies show that the pressure-flow relationship on the x-y recorder is only dependent on the ostial diameters, while hysteresis in the curve sometimes observed is due to ostial diameters, sinusal volumes and air-flow rates. All calculations have been performed at an air-flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$, which is the most suitable air-flow for calculation of the ostial resistance of the different ostial models used in the experiment. This air-flow might also be created during nasal breathing in humans. A constant artificial air-flow of one liter per minute into the sinus model ($16.7 \text{ cm}^3 \cdot \text{s}^{-1}$) was selected in method III. Results comparable to those obtained by Aust & Drettner (1974) were achieved. However, at small ostia (0.22-0.60 mm) the constant artificial air-flow had to be reduced to $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ in order to obtain measurable pressure differences in our model studies. Despite this reduction, the ostial diameter of 0.22 mm was not measurable.

The most correct way to express ostial patency is to use the ostial resistance according to the formula $R_o = \frac{P_o}{\dot{V}_o}$ in mm H₂O/ $1000 \text{ cm}^3 \cdot \text{s}^{-1}$. For clinical praxis however, the functional size as a cross section area (Aust & Drettner, 1974) or the equivalent ostial diameter are practical alternatives to expressing the ostial resistance.

The ostial resistances, obtained with methods II and III, are not comparable due to the two different air-flow levels used. However, if the ostial resistance is transformed into the equivalent ostial diameter in mm, the values obtained are comparable (Jannert et al., 1982a).

Ostial resistance can be calculated with method II during both expiration (sinu-nasal direction) and during inspiration (naso-sinusal direction), while the ostial resistance with method III is only measurable in the sinu-nasal direction.

In conclusion, these three different patency test methods can all be carried out with the same piece of equipment which offers unique possibilities for static as well as dynamic evaluation of the ostial function. With the pressure-flow method (II) the ostial resistance can be measured in the naso-sinusal as well as in the sinu-nasal direction in model experiments at an air-flow of

$2.0 \text{ cm}^3 \cdot \text{s}^{-1}$. The resistance values obtained with methods II and III are not directly comparable because of different air-flow levels. However, by transformation into an equivalent ostial diameter, the values found with the dynamic method II are comparable to values obtained with the static method III.

The actual equipment experimentally tested on a rigid nose-sinus model has also been evaluated on healthy volunteers before clinical studies were performed (Jannert et al., 1982a,b).

ZUSAMMENFASSUNG

Die Funktion bei Modellostien (Durchmesser 0.22-4.7 mm) ist in Experimenten an einem Nasennebenhöhlenmodell ausgewertet worden. Eine Pistonpumpe, die ein Luftvolumen von 467 cm^3 pro Umdrehung gibt, ist mit den Geschwindigkeiten 10 und 20 Umdrehungen pro Minute angewendet worden. Die Ostienfunktion ist bei Nebenhöhlenvolumen von 2, 5, 15 und 25 cm^3 registriert worden.

Drei verschiedene Registrierungsmethoden sind im Modell-experiment angewendet und verglichen worden. Methode I: gleichzeitige Registrierung der Druckvariation in Nebenhöhle und Nase. Methode II: gleichzeitige Registrierung des Differentialdruckes zwischen Nebenhöhle - Nase und des Luftstroms durch das Ostium. Methode III: Registrierung der Druckerhöhung in der Nebenhöhle, wenn ein konstanter artifizieller Luftstrom von $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ oder $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ dem Nebenhöhlenmodell zugeführt wird.

Mit der ersten Methode fand man, dass die Druckvariationen in Nebenhöhle und Nase von Ostiendiameter, Nebenhöhlenvolumen und Geschwindigkeit der Pistonpumpe beeinflusst wurden; deshalb ermöglicht diese Methode keine isolierte Bestimmung der Ostienfunktion.

Die Druck-Strömungsrelation, die mit der zweiten Methode registriert wurde, war nur vom Ostiendiameter abhängig; deshalb kann diese Methode für eine isolierte Bestimmung der Ostienresistenz und des equivalenten Ostiendiameters angewendet werden.

Die dritte Methode ist vom Nebenhöhlenvolumen unabhängig; deshalb kann diese statische Methode auch angewendet werden, um Ostienresistenz und den equivalenten Ostiendiameter zu berechnen.

Die numerischen Werte des equivalenten Ostiendiameters, die mit den zweiten und dritten Methoden berechnet wurden, hatten in diesem Modellexperiment eine gute Übereinstimmung.

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PATENCY OF THE MAXILLARY SINUS OSTIUM IN HEALTHY INDIVIDUALS

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Abstract. In a group of 20 healthy subjects the patency of the maxillary ostium has been evaluated in 35 maxillary sinuses with three different techniques: simultaneous pressure recording in the sinus and the ipsi- and contralateral nasal cavity; simultaneous recording of differential pressure between the sinus and the ipsilateral nasal cavity and air-flow through the ostium during nasal breathing; recording of the pressure rise in the sinus with an artificial air-flow of 1 litre per minute applied to the sinus. The tests were carried out in sitting and recumbent positions. In 5 persons (10 sinuses) a retest was performed after 2 months. These subjects were also tested with an inflatable neck cuff in order to obtain an increased venous pressure. Rhinomanometry at rest and after physical effort was also performed. The pressure relationship between the maxillary sinus and the ipsilateral nasal cavity was 1:1 in both the sitting and the recumbent positions, but < 1 when the contralateral nasal cavity was measured. Pressure recording alone gives no quantitative information about the patency of the ostium. Determination of the ostial resistance during nasal breathing could be performed in 13 sinuses but in the remaining 22 sinuses the ostia were too wide to give a measurable resistance. The equivalent ostial diameter during inspiration could be estimated in 12 of the sinuses from a diagram constructed from known ostial diameters in model experiments. With an artificial air-flow applied into the sinus, the equivalent ostial diameters could be estimated from the diagram in all cases. No statistical difference was found in comparable cases between the mean equivalent ostial diameters estimated with the two methods. The equivalent ostial diameters showed a statistically significant reduction in the recumbent position and after application of the neck cuff. A statistically significant relationship was also found between the airway resistance of the nasal cavity and the equivalent diameter of the ostium in sitting and recumbent positions. Such a relationship could not be found between the equivalent ostial diameters measured at rest and the nasal resistance recorded after physical effort.

It is a generally accepted fact that free air communication between the nasal cavity and its paranasal sinuses via patent ostia is a pre-requisite for physiological conditions within the sinuses (Mann, 1977). Obstruction leads to a low oxygen tension within the sinuses (Aust & Drettner, 1974a) which seems to be of great importance in the pathogenesis of sinusitis (Flottes et al., 1960; Naumann, 1964). Braune & Clasen (1877) showed in experiments on autopsy specimens that nasal pressure variations could be transmitted to the maxillary sinuses. However, in spite of many ostial investigations, opinions still differ about what is normal or abnormal, mostly depending on different ways of expressing the ostial function. Furthermore, most of the investigations have been performed on diseased sinuses with few measurements on healthy ones.

Therefore, we thought it worth-while to study the ostial function in healthy individuals using three different test methods: simultaneous measurements of pressure changes in the nose and the maxillary sinus during nasal breathing (Method I), measurements of differential pressure and air-flow between sinus and nose during nasal breathing (Method II), and differential pressure recording at a constant artificial air-flow applied into the sinus (Method III). The special aims have been:

- to compare the pressure relation between the maxillary sinus and the nasal cavity;
- to measure the airway resistance of the maxillary ostium and to estimate the equivalent ostial diameter using two different techniques;
- to study effects of posture and increased venous pressure on the size of the ostium; and
- to ascertain if any relationship exists between nasal resistance and ostial diameter.

METHODS

Cannula equipment

After local anaesthesia of the mucosa a cannula was introduced through the canine fossa. The mandrine was replaced by a cannula for measurement, which was tightly connected to the cannula of

punction. For details, see Ivarsson et al. (1982).

Rhinomanometry

The nasal airway resistance was recorded with anterior rhinomanometry during spontaneous respiration x-y wise on an oscilloscope (Broms, 1980). The airway resistance of the nasal cavity was calculated according to Broms (1980). Statistical evaluation was performed from a mathematically calculated angle v_2 (Broms, 1980). This angle is convertible into a resistance value R_2 in $\text{cm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ using the equation $10 \cdot \tan v_2 = R_2$.

Pressure recording (Method I)

A small tube for pressure recording in the cannula of measurement made an air-tight connection via a polyethylene catheter to a pressure transducer. The ipsilateral nasal cavity was sealed with "Leukoflex" tape and bypassed by a polyethylene catheter connected to an identical pressure transducer. The amplified pressure signals were recorded on an ink jet recorder and also recorded onto tape using an FM tape recorder at a speed of 15 inches per second (ips) for later analysis of the pressure transmission on an x-y recorder. In model experiments it was found that with a tape recorder speed from 15 ips to $1 \frac{7}{8}$ ips no hysteresis was observed, on the x-y recorder, in nasal pressure (P_n) versus sinus pressure (P_s) when the ostial diameter was $\geq 0.6 \text{ mm}$ at a sinus volume up to 25 cm^3 and nose pressure changes up to $27 \text{ mm H}_2\text{O} \cdot \text{s}^{-1}$. For details, see Ivarsson et al. (1982).

Differential pressure and flow recording (Method II)

The air-flow through the ostium was measured with a flow meter open to the atmosphere. The flow meter consisting of a resistor and a differential pressure transducer was connected to the tube for flow measurement. The ipsilateral nasal cavity was sealed with "Leukoflex" tape and bypassed by two polyethylene catheters. One of the catheters was connected to a pressure transducer for nasal pressure recording, while the other was connected to a differential pressure transducer, which was also linked to the pressure recording tube in the cannula of measurement. The nasal pressure (P_n), the pressure difference (P_o) between the sinus and

the ipsilateral nasal cavity as well as the air-flow ($\dot{V}_O$) through the ostium was recorded on an ink jet recorder and recorded onto tape as described in method I.

After the experiments the differential pressure (P_O) across the ostium versus the flow through the ostium ($\dot{V}_O$) was analysed on an x-y recorder. There was always a small hysteresis in the pressure-flow curve depending on the volume of the sinus. This hysteresis increased with increasing volume of the sinus. In order to calculate the pressure-flow characteristics of the ostium a mean value curve was created where the differential pressure across the ostium was calculated at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$. In model experiments it was found that in ostia exceeding 2.5 mm in diameter the pressure difference obtained was $< 0.05 \text{ mm H}_2\text{O}$ at the flow mentioned and the pressure difference could therefore not be measured exactly. For details, see Ivarsson et al. (1982).

Differential pressure recording with a constant artificial air-flow (Method III)

The equipment and arrangement used was the same as in method II. An air-flow of 1 liter per minute ($\dot{V}_O = 16.7 \text{ cm}^3 \cdot \text{s}^{-1}$) adjusted by means of a constant flow regulator was introduced into the sinus via the cannula of measurement. The release of air into the sinus was switched on and off by a valve. The differential pressure across the ostium during the constant artificial air-flow was recorded on an ink jet recorder. During this period no breathing was allowed. The differential pressure, recorded with an artificial air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$, was transferred to the diagram prepared from model experiments (Fig. 1), from which the equivalent ostial diameter could be estimated. For details, see Ivarsson et al. (1982).

Calibration

Calibration and frequency balance control of the equipment for recording P_N , P_S , P_O and $\dot{V}_O$ were performed before and after each test.

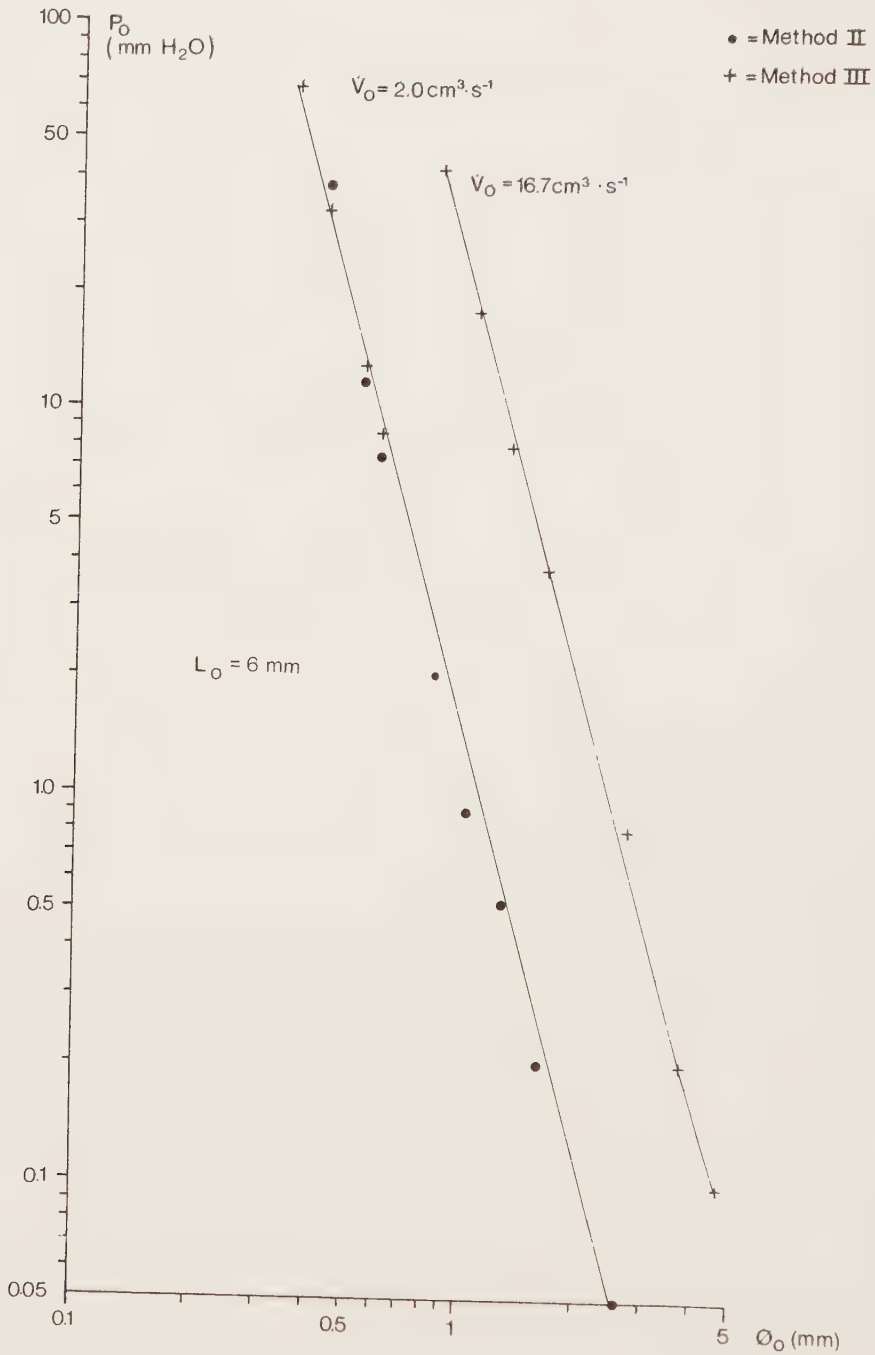


Fig. 1. Diagram for estimation of the equivalent ostial diameters from the pressure-flow relationship at $\dot{V}_O = 2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method II) and pressure increase at constant artificial air-flows of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ and $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method III).

Estimation of equivalent ostial diameters

The ostia were assumed to be circular with a length of 6 mm (Ivarsson et al., 1982). A diagram (Fig. 1) obtained from model experiments of known "ostial diameters" from the pressure-flow relationship at $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method II) and from the pressure increase at an artificial constant air-flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ or $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method III) has been used for estimating the equivalent ostial diameters. The artificial flow level used for estimation of the ostial diameter (Method III) was $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$. As seen from Fig. 1 diameters between 0.34 mm to 4.7 mm can be measured. Theoretically, ostia with diameters $< 0.34 \text{ mm}$ and $> 4.7 \text{ mm}$ can be estimated by extrapolation from the diagram, but this was not necessary in this study.

MATERIAL

The test subjects were selected according to current ethical agreement and consisted of 20 healthy individuals (9 ♀ and 11 ♂) aged 22-36 years ($\bar{x}=26$ years). Thirty-five maxillary sinuses were investigated. Two months after the initial investigation, retests were performed on 10 maxillary sinuses in 5 persons (2 ♀ and 3 ♂). The selection criteria for a healthy sinus were as follows:

- no earlier sinusitis or trauma to the area of the nose and/or sinus. No allergic disease or present upper respiratory tract infection;
- normal findings during anterior and posterior rhinoscopy;
- normal findings of sedimentation rate, leucocytes, erythrocytes, diff. count, total eosinophilic count and PRIST, as well as normal nasal smears as regards eosinophilic leucocytes;
- normal sinus radiography in three standard projections;
- normal sinus ultrasonic examination (Jannert et al., 1981);
and
- normal sinoscopy (Olympus fiberscope Ø 1.7 mm^{*})

* ENF-P A1988 Olympus Corporation of America, 4 Nevada Drive, N.Y. 11042, U.S.A.

TEST PERFORMANCE

The examination started with rhinomanometry as described by Broms (1980). Each volunteer was tested with anterior rhinomanometry at rest in sitting and recumbent positions and after well defined physical exercise. Local anaesthesia (1-2 ml carbocain 5 mg.ml⁻¹) was injected into the mucosa of the right canine fossa. The right maxillary sinus was punctured with the cannula equipment earlier described. The position of the cannula within the sinus was checked with a fiberscope and the mucosa was photographed. In the sitting position the pressure changes in the nose and sinus were simultaneously recorded during nasal breathing (Method I). Hereafter the pressure difference between the sinus and the nose and the air-flow through the ostium was measured simultaneously during nasal breathing (Method II). Finally, the pressure difference across the ostium was recorded when a constant flow of 16.7 cm³.s⁻¹ was introduced into the maxillary sinus and through the ostium (Method III).

The above procedures were repeated after 5 minutes in the recumbent position and method I was included with forced inspiration (sniff-test) and Toynbee's manoeuvre. Afterwards the "Leukoflex" tape was moved to the other nostril and pressure recording was performed simultaneously in the sinus and the contralateral nasal cavity (Method I). In order to check the intrasinus conditions, sinuscopy was employed at the end of the test.

The same measurements were then repeated on the left maxillary sinus. Finally, a second rhinomanometry was done in sitting and recumbent positions in order to reveal any influences of the test performance on the nasal resistance.

A retest 2 months later was performed with the same procedure as described above except for radiography. The recordings with methods II and III were done as described and also with an inflatable cuff placed around the neck. The recordings were performed before pressure application of the cuff, and then, the cuff was inflated to 25 mm Hg (340 mm H₂O). Finally, new recordings were performed with the cuff inflated in an upright position after 2 and 5 minutes, respectively.

RESULTS

Rhinomanometry

The resistance of the nasal cavities was measured at rest in sitting and recumbent positions and in the sitting position after physical effort. The results were all within the limits of normal subjects (Broms, 1980). No statistically significant difference was obtained between the first and second investigation ($p > 0.05^*$).

Sinu-nasal pressure relationship (Method I)

During simultaneous pressure recording in the sinus (P_s) and the ipsilateral nasal cavity (P_{in}) up to ± 50 mm H₂O no hysteresis was found. The pressure relationship ($\frac{P_s}{P_{in}}$) was 1:1 during inspiration and expiration, both in the sitting and recumbent positions. This means that identical pressures were recorded within the sinus and the ipsilateral nasal cavity.

Simultaneous pressure recording in the sinus and the contralateral nasal cavity (P_{cn}) was only performed in the recumbent position. The pressure relationship between the sinus and the contralateral nasal cavity ($\frac{P_s}{P_{cn}}$) was 0.82 (S.E. ± 0.02) during inspiration ($P_{cn} = 50$ mm H₂O) and 0.82 (S.E. ± 0.02) during expiration ($P_{cn} = 50$ mm H₂O), which means no statistically significant difference ($p > 0.05$). However, both values differed significantly from the pressure relationship between the sinus and the ipsilateral nasal cavity ($p < 0.05$), which means that lower pressures were found within the sinus as compared to the contralateral nasal cavity. Toynbee's manoeuvre as well as the "sniff-test" showed measurable pressure changes within the sinuses in all cases.

* Paired t-test was used to establish whether or not there was a statistical difference between two sets of data.

Calculation of the ostial airway resistance (Method II)

During inspiration in the sitting position 15 out of 35 sinuses showed a differential pressure of $> 0.05 \text{ mm H}_2\text{O}$ at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Fig. 2). During expiration in the sitting position a differential pressure of $> 0.05 \text{ mm H}_2\text{O}$ was found in 14 sinuses. In 13 of the 35 sinuses (Fig. 2) the resistance of the ostium could be directly compared both during in- and expiration in the sitting position. The mean resistance among these 13 sinuses was $157.3 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ (S.E. ± 37.9 ; range 40-475) during inspiration and $150.4 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ (S.E. ± 32.9 ; range 40-400) during expiration and the difference was not statistically significant ($p > 0.05$).

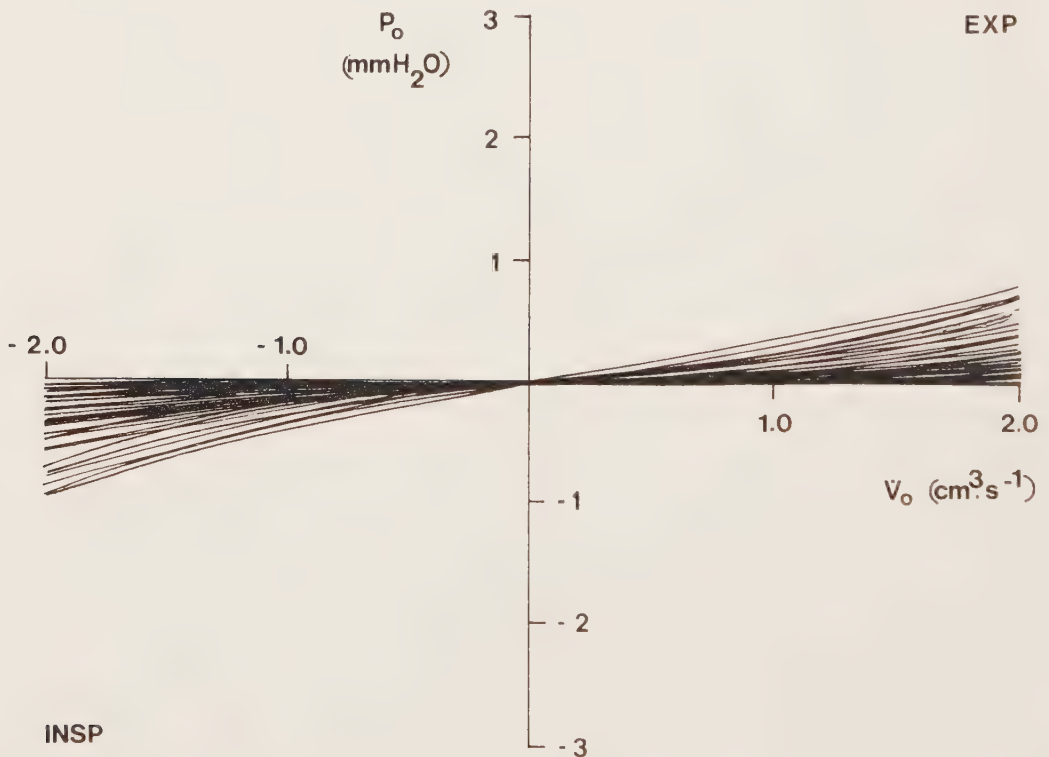


Fig. 2. Differential pressure- and air-flow recordings during nasal breathing in the sitting position in 35 healthy sinuses (Method II).

In the recumbent position the pressure difference and the resistance could be measured in 16 sinuses during inspiration and in 15 sinuses during expiration. Direct comparisons were possible in 13 sinuses. The mean ostial resistance during inspiration was $220.4 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ (S.E. ± 44.5 ; range 65-565) and during expiration $184.2 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ (S.E. ± 44.6 ; range 50-625). The difference was not statistically significant ($p > 0.05$). When comparing the resistance of the ostium during inspiration in sitting and recumbent positions (see above) the difference was statistically significant ($p < 0.05$) with higher values in the recumbent position.

Estimation of the equivalent ostial diameter (Method II)

In 12 sinuses (Fig. 2) the equivalent ostial diameter during inspiration was estimated from the diagram (Fig. 1). The equivalent ostial diameters were compared in sitting and recumbent positions. The mean equivalent ostial diameter in the sitting position was 1.70 mm (S.E. ± 0.1 ; range 1.10-2.20) and in the recumbent position 1.47 mm (S.E. ± 0.09 ; range 1.10-2.05). The difference was statistically significant ($p < 0.001$). In the remaining 23 sinuses direct comparison could not be made as the pressure difference did not exceed 0.05 mm H₂O in all measurements.

Equivalent ostial diameters in sitting and recumbent positions (Method III)

The mean value of the ostial diameter in the sitting position in 35 sinuses, measured with method III, was 2.54 mm (S.E. ± 0.13 ; range 1.13-4.5) (Fig. 3).

In the recumbent position the mean value for the same 35 sinuses was 2.30 mm (S.E. ± 0.13 ; range 0.95-4.5) (Fig. 3). The difference between sitting and recumbent positions was statistically significant ($p < 0.001$).

The mean value of the ostial diameter in the sitting position for female and male subjects is shown in Table I. The difference was not statistically significant ($p > 0.05$).

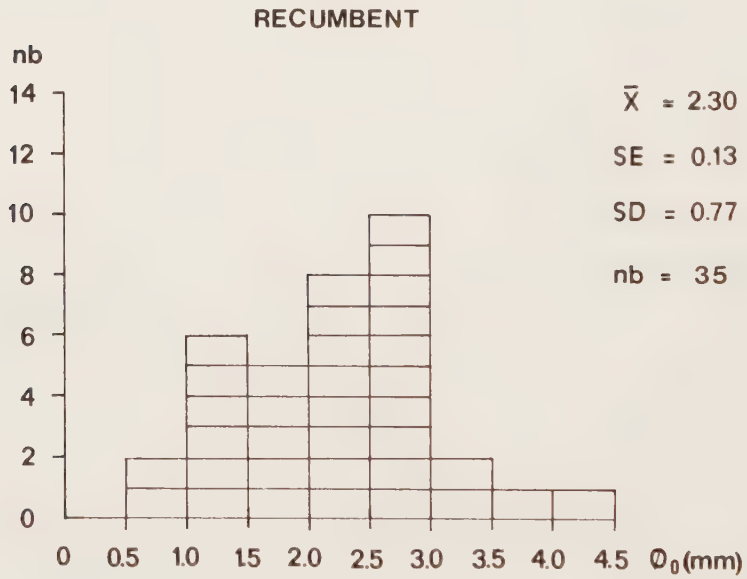
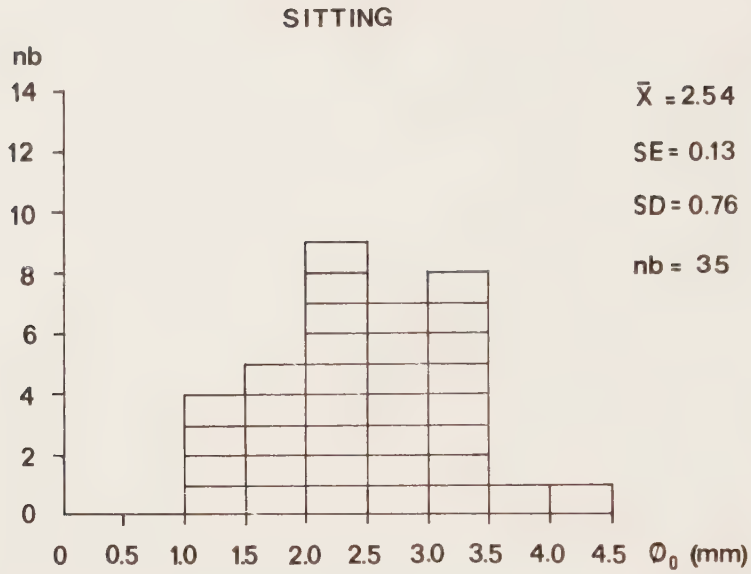


Fig. 3. Equivalent ostial diameters in sitting and recumbent positions estimated in 35 sinuses (Method III).

Table I. *The mean equivalent ostial diameters in mm according to sex (Method III).*

	Sitting position					
	Dexter			Sinister		
	<u>No.</u>	<u>Ø</u>	<u>S.E.</u>	<u>No.</u>	<u>Ø</u>	<u>S.E.</u>
Female	7	2.40	(± 0.22)	9	2.26	(± 0.23)
Male	9	2.74	(± 0.19)	10	2.70	(± 0.33)

Comments: A comparison of the ostial resistance calculated with methods II and III is not possible as the differential pressure (P_o) has been recorded at two different air-flow velocities (Method II: $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$; Method III: $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$). Because of this, the equivalent ostial diameters have been estimated with methods II and III thereby making direct comparisons possible between the methods.

Equivalent ostial diameters following increased venous pressure (Method III)

The influence of increased venous pressure was studied in 10 sinuses (Method III). The neck was compressed with a cuff for 5 minutes and the equivalent ostial diameter decreased in all cases. The mean value before compression was 2.87 mm (S.E. ± 0.32 ; range 1.55-4.50). After 2 minutes of compression the mean value was 2.57 mm (S.E. ± 0.39 ; range 0.82-4.50) and after 5 minutes 2.46 mm (S.E. ± 0.35 ; range 1.08-3.75). The difference (about 10 % and 14 %, respectively) between the values before and after compression was statistically significant ($p < 0.05$). The equivalent ostial diameters measured after 5 minutes of neck compression in sitting position ($\bar{x}=2.46$; S.E. ± 0.35 ; range 1.08-3.75) did not differ statistically from those without cuff in recumbent position ($\bar{x}=2.48$; S.E. ± 0.28 ; range 0.98-3.75).

Comparisons between equivalent ostial diameters estimated with methods II and III

A comparison of the equivalent ostial diameters estimated with methods II and III was possible in 12 sinuses (Fig. 4). The equivalent ostial diameters did not differ significantly ($p > 0.05$) either in sitting or in recumbent positions (Table II).

Equivalent ostial diameters in relation to ipsilateral nasal resistances

When the airway resistance of the nasal cavity at rest, expressed as an angle (v_2), (Broms, 1980) and the equivalent ostial diameters of the ostium were estimated with method III, a statistically significant relationship was found between the airway resistance of the ipsilateral nasal cavity and the equivalent ostial diameter both in sitting and recumbent positions (Fig. 5). The regression coefficients (B) are statistically different from zero ($p < 0.05$) both in sitting (Fig. 5:1) and recumbent positions (Fig. 5:2). This means that a high airway resistance in the nasal cavity corresponds to a small equivalent ostium and vice versa. The regression coefficients in sitting and recumbent positions are not statistically separated from each other ($p > 0.05$). When studying the ipsilateral nasal airway resistance after physical effort with the equivalent ostial diameter, estimated with method III in sitting position the regression coefficients did not differ significantly from zero ($p > 0.05$) (Fig. 6).

Results of retest

The reliability of the initial experiments with the three methods was investigated by a retest of 10 sinuses after an interval of 2 months. The results obtained with the different ostial test methods in the sitting as well as in the recumbent position did not differ statistically between the test and the retest. When comparing the first and second rhinomanometry after physical effort the values were still within the limits of normal subjects (Broms, 1980).

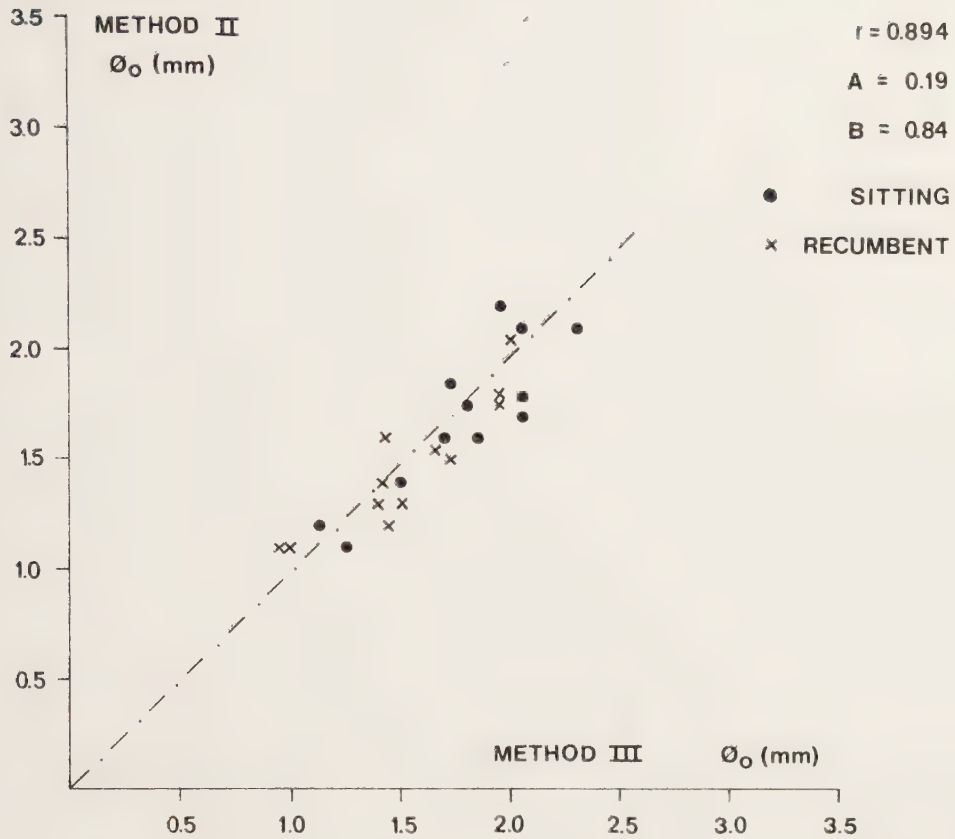


Fig. 4. Comparison between equivalent ostial diameters estimated in 12 sinuses with methods II and III. The interrupted line represents a relationship of 1:1.

Table II. Comparison between mean equivalent ostial diameter in mm in 12 sinuses measured with methods II and III.

	Method			
	II		III	
	$\bar{x}$	S.E.	$\bar{x}$	S.E.
sitting	1.70	(± 0.1)	1.78	(± 0.1)
recumbent	1.47	(± 0.09)	1.54	(± 0.1)

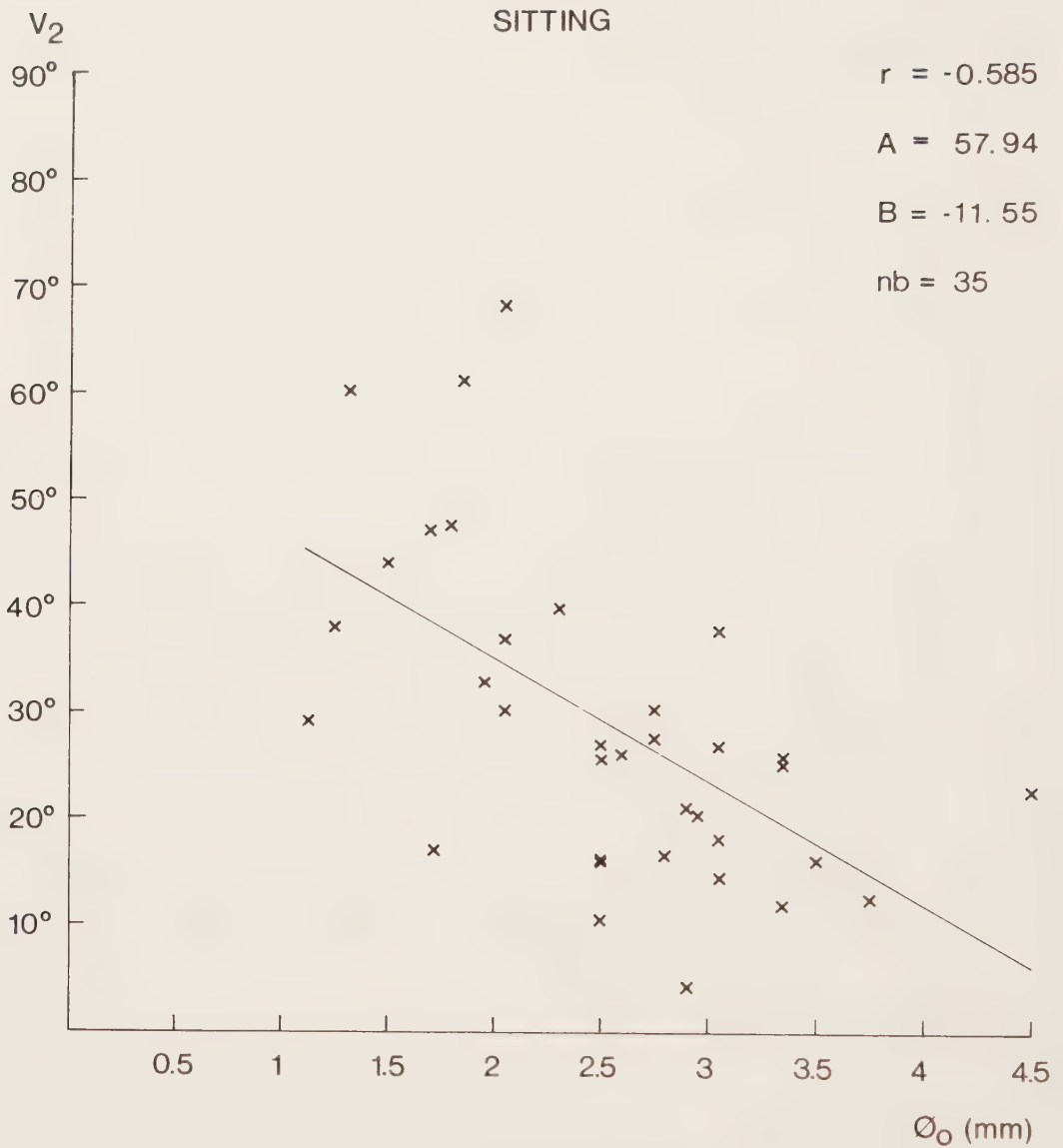


Fig.5:1. The airway resistance (v_2) of the ipsilateral nasal cavities at rest compared to the equivalent ostial diameters estimated at rest in sitting position with method III. The regression coefficient B is statistically separated from zero.

RECUMBENT

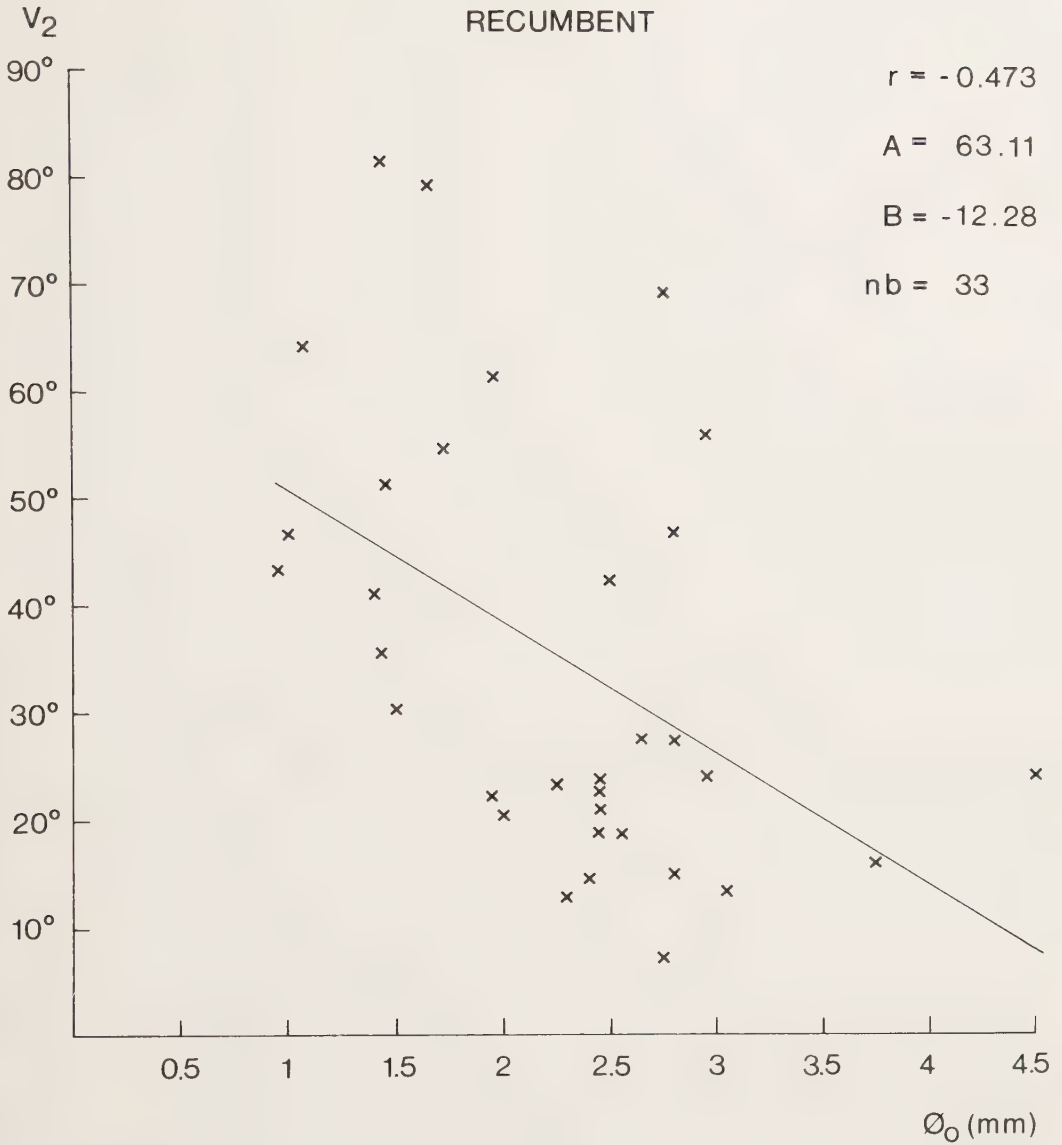


Fig.5:2. The airway resistance (v_2) of the ipsilateral nasal cavities at rest compared to the equivalent ostial diameters estimated at rest in recumbent position with method III. The regression coefficient B is statistically separated from zero.

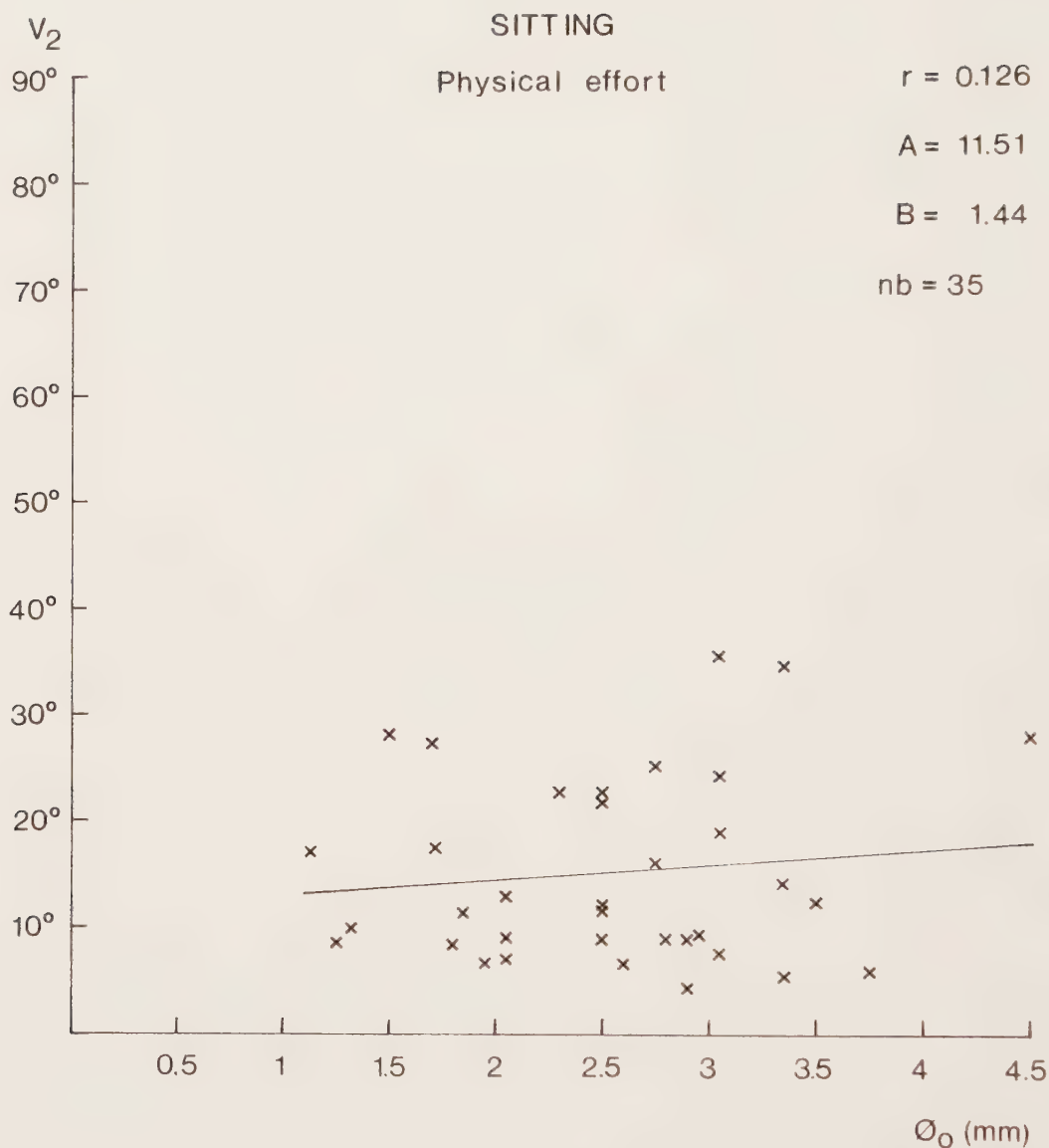


Fig. 6. The airway resistance (v_2) of the ipsilateral nasal cavities after physical effort compared to the equivalent ostial diameters estimated at rest (sitting) with method III. The regression coefficient B is not statistically different from zero.

DISCUSSION

In the present study puncture of the canine fossa was used to introduce a cannula into the sinus. This made simultaneous antral pressure-flow recording and ipsilateral anterior rhinomanometry easy to perform. Moreover, the distance between the ostium and the site of puncture is longer than if puncture through the lateral nasal wall is done. Aust et al. (1977) noticed that the introduction of a cannula through the lateral nasal wall in patients complaining of symptoms of rhinitis or sinusitis caused a mucosal swelling which diminished the functional size of the ostium. This problem may not arise with the canine fossa puncture.

In order to avoid the risk of air embolism the position of the cannula was checked by the use of a fiberscope small enough to pass through the cannula of puncture. This was done to ensure that the tip of the cannula was free in the sinus cavity.

Recording during spontaneous breathing (Methods I and II) was always done first to ensure that the ostium was open which reduced the risk of too high intrasinus pressure increase when method III was used. Flottes et al. (1960) postulated that there was no risk for air embolism if the pressure rise did not exceed 200 mm H₂O. In this study no higher pressure rise than 25 mm H₂O was observed at a flow of 16.7 cm³.s⁻¹ (Method III).

Pressure recording within the sinus and nasal cavity can be performed either simultaneously (Proetz, 1932; Drettner, 1965) or consecutively (Rantanen & Kortekangas, 1971). In the present study simultaneous recording was used as the consecutive method has some disadvantages. For example, the nasal cycle may interfere with the results and it is hard to breathe exactly in the same manner during both the antral and nasal pressure recordings.

The pressure recording can be made either on the ipsilateral side (Proetz, 1932; Drettner, 1965) or on the contralateral side (Kortekangas & Rantanen, 1976). In the present study recordings from both sides were used. When measuring antral pressure and ipsilateral nasal cavity pressure identical pressure variations were found as described by Proetz (1932) and Drettner (1965). When the contralateral recording method was used, lower pressure changes were found in the sinus compared with the nasal cavity. This is in accordance with Fischer (1969) who found that there is

a pressure contribution to the posterior nasal cavity although it is small compared with the pressure changes created in the anterior part of the nasal cavity. Ipsilateral recording thus seems to be the most physiological method. Time-lag, as described by Drettner (1965), was not observed in any of the cases, indicated by the absence of hysteresis in the pressure transmission between the nasal cavity and the sinus, when recorded on the x-y diagram.

As the pressure changes within the sinus and the nasal cavity were identical during simultaneous ipsilateral recording, there was no possibility of performing a quantitative analysis of the ostial patency with this method. In the present study simultaneous ipsilateral recording was used to ensure that the ostium was patent and it was also possible to detect any leakage in the equipment which might cause imbalance in the recording system.

When the ostial resistance was estimated during nasal breathing (Method II) the pressure difference between the nasal cavity and the sinus was recorded at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ through the ostium. This flow level is considerably higher than the physiological flow through the ostium during spontaneous breathing as the maxillary sinus is a closed cavity. Svanholm et al. (1981) found that the mean volume of air passing through the ostium in one breath was 0.02 cm^3 . In the present study the recordings were performed with the equipment open to the atmosphere giving much higher flow levels than in a closed sinus cavity. In order to obtain measurable pressure differences across the ostium the present flow level ($2.0 \text{ cm}^3 \cdot \text{s}^{-1}$) was chosen.

The number of sinuses showing measurable ostial resistance varied from 14 during expiration in sitting position to 16 during inspiration in recumbent position. No statistically significant difference was found between the resistance values for inspiration and expiration neither in sitting nor in recumbent positions. When the volunteers were placed in the recumbent position, a significant increase ($p < 0.05$) of the resistance during inspiration was found as compared with the sitting position. This increase could not be proved for expiration. Thus, it seems that the position of the patient affects the ostial resistance more than the respiration phase.

The estimation of the equivalent ostial diameters with a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ can be made from the diagram (Fig. 1), but the method is restricted to equivalent ostial diameters $< 2.5 \text{ mm}$, as pressure differences $< 0.05 \text{ mm H}_2\text{O}$ are not measurable with this method. This restriction seems to be of minor clinical importance as ostia with a diameter $> 2.5 \text{ mm}$ seem to be large enough to maintain a normal oxygen content within the sinus (Aust & Drettner, 1974a).

The mean value of the ostial diameter obtained with method III in the sitting position (2.54 mm) is in agreement with the results from a group of 37 healthy subjects described by Aust & Drettner (1974b), who found a mean diameter of 2.4 mm . In the recumbent position the mean equivalent ostial diameter was 2.30 mm in the present study and the corresponding figure reported by Aust & Drettner (1975) was 1.90 mm . This difference might be due to varying ways of inserting the trocar. Aust & Drettner (1975) used the medial sinus wall, which might cause an oedema, thereby decreasing the ostial diameter. In the present study this risk is diminished as the frontal wall of the maxillary sinus was punctured. The reduction of the ostial diameters was statistically significant in both investigations. The same effect of the body position on the mucosal congestion of the nose and Eustachian tube was shown by Rundcrantz (1969a,b).

Direct comparison between ostial diameters estimated with methods II and III showed a good conformity in spite of great differences in the flow level of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ and $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$, respectively. In the present study the greatest pressure increase (Method III) was $25 \text{ mm H}_2\text{O}$. In cases with an obstructed ostium, e.g. in sinusitis, the increased sinus pressure might decongest the swollen mucosa thereby forcing it more open.

When the neck cuff was inflated the ostial diameters decreased successively with the duration of the neck compression. The mean ostial diameter (2.46 mm) after 5 minutes of compression in sitting position was almost identical with the corresponding mean value in recumbent position (2.48 mm) without compression. This is in accordance with the findings of Rundcrantz (1969b). Aust & Drettner (1975) also found a reduction of the ostial diameters when a neck cuff was used, corresponding to the ostial diameters in a body position 20° from the horizontal plane. The difference

between these results and the present study might depend on the fact that our observations were made 2 and 5 minutes after the application of the inflated cuff. Aust & Drettner (1975) did not report the time interval between the cuff application and their observations.

A comparison between nasal airway resistance and the equivalent ostial diameters has, as far as we know, not been reported in literature. A relationship was found statistically between an increasing resistance of the ipsilateral nasal cavity and a decreasing equivalent ostial diameter both in sitting and recumbent positions. This statistical relationship did not exist between the nasal airway resistance values after physical effort and the equivalent ostial diameters at rest in the sitting position. Because of technical reasons the equivalent ostial diameters could not be recorded after physical effort. This statistical relationship between nasal airway resistance and the equivalent ostial diameters gives an expression of the vascular conditions of the mucosa in the nasal cavity which reacts on different stimuli as e.g. physical effort or body position.

In conclusion, the pressure-flow method (II) makes it possible to measure the ostial resistance during nasal in- and expiration. As far as we know, the dynamic approach has not been used in this connection before. The method is limited to ostial resistances $\geq 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ but this of minor clinical importance as ostial resistance $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ (ostium $> 2.5 \text{ mm}$) indicates a normal function of the ostia (Aust & Drettner, 1974a). This is in accordance with Mann (1977) who stated that a normal acting ostium does not have any measurable resistance. In cases with an increased ostial resistance exceeding $25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ the equivalent ostial diameter can be evaluated. This is of clinical importance for a quantitative evaluation of the ostial function in diseased sinuses. The pressure recording method (I) gives mostly qualitative information about the ostium, whereas the different pressure air-flow method (III) is a static way to determine the sinu-nasal resistance and equivalent ostial diameter. The three different methods have also been used for diagnostic purposes in a clinical material (Jannert et al., 1982).

ZUSAMMENFASSUNG

In einer Serie, umfassend 35 gesunde Kiefernebenhöhlen, ist die Funktion des Ostiums der Kiefernebenhöhle mit drei verschiedenen Techniken studiert worden: gleichzeitige Druckmessung in der Kiefernebenhöhle und Nasenkavität; gleichzeitige Registrierung des Differentialdruckes zwischen Kiefernebenhöhle und der Nasenkavität derselben Seite zusammen mit der Strömungsregistrierung des Luftstromes durch das Ostium bei Nasenatmung; Registrierung der Druckerhöhung in der Kiefernebenhöhle, wenn ein artifizieller Strom von 1 Liter pro Minute der Kiefernebenhöhle zugeführt wurde. Die Untersuchungen wurden in sitzender und liegender Stellung durchgeführt. In 10 Fällen wurde eine Blutdruckmanschette um den Hals der Versuchsperson gelegt und die Manschette wurde bis zu einem Druck von 340 mm H₂O aufgeblasen. Die Nasenwiderstandsmessung wurde in sitzender und liegender Stellung und nach Arbeitsbelastung durchgeführt.

Die Druckrelation zwischen Kiefernebenhöhle und der gleichseitigen Nasenkavität war in allen Fällen 1:1 sitzend und liegend, aber weniger als 1, wenn die Druckregistrierung zwischen Kiefernebenhöhle und der entgegengesetzten Nasenkavität vorgenommen wurde. Die Druckregistrierung gibt keine quantitative Information über das Ostium. Die Bestimmung der Ostienresistenz bei Nasenatmung konnte in 13 Fällen vorgenommen werden, aber in den restlichen 22 Fällen war die Ostienresistenz zu klein, um gemessen werden zu können. Der Ostiumdiameter, gemessen mit der Druck-Strömungs-Methode, konnte in 12 Fällen von einem Diagramm berechnet werden, das mit Ausgangspunkt in einem Modellexperiment mit bekannten Ostiendiametern konstruiert wurde. Mit Hilfe eines artifiziellen Luftstromes von 1 Liter pro Minute konnten die Ostiendiameter auch von demselben Diagramm, das früher genannt wurde, berechnet werden. Es bestand kein statistischer Unterschied zwischen den Ostiendiametern, die mit den beiden Methoden errechnet wurden. Die Ostiendiameter zeigten eine statistische signifikante Reduktion in liegender Stellung und nachdem eine Blutdruckmanschette um den Hals der Versuchsperson angebracht worden war. Man fand auch einen statistischen Zusammenhang zwischen den Nasenwiderständen und den gleichseitigen Ostiendiametern, gemessen in Ruhe, und Nasenwiderständen, gemessen nach physischer Arbeit, beobachtet werden.

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STUDIES OF THE MAXILLARY OSTIAL FUNCTION IN CASES WITH
MAXILLARY PAIN, INTRASINUSAL CYSTS AND CHRONIC SINUSITIS

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Abstract. The maxillary ostial function, measured as pressure transmission capacity, ostial airway resistance, equivalent ostial diameter during nasal breathing and with a constant artificial air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ into the sinus, was compared in three groups of patients. One group consisted of 7 sinuses in 6 patients with maxillary pain but without any signs of sinusitis; a second group of 6 sinuses in 6 patients with intra-maxillary cysts; and a third group of 6 sinuses in 5 patients with chronic maxillary sinusitis. No impairment of the ostial function was found in groups one and two. In the third group an increased airway resistance of the ostia and small equivalent ostial diameters were found both in sitting and recumbent positions. With the pressure recording technique, the ostium can be judged as patent, non-patent or partially obstructed but no further grading can be done. With the pressure-flow technique the ostial function can be evaluated as ostial resistance or equivalent ostial diameters under "physiological conditions" when the ostium is patent. With a constant artificial air-flow into the sinus the equivalent ostial diameter can be estimated even in non-patent ostia but the equivalent ostial diameters obtained do not always reflect the true functional state of the ostium.

The function of the maxillary ostium in patients with sinus diseases has been a source of interest since Braune & Clasen (1877) made the first intramaxillary pressure recordings. Kerekes (1935) found that the respiratory pressure variations seen in normal maxillary sinuses were lacking in cases of sinusitis. Drettner (1965a) simultaneously measured nasal and maxillary sinus pressure variations in a series of 36 sinuses with chronic sinusitis and found that the ostium was closed in all cases. Similar results were obtained by Kortekangas & Rantanen (1976) using consecutive pressure recordings in the sinus and the contralateral nasal cavity.

Calculation of the ostial resistance defined as the pressure necessary to initiate a flow of saline solution or gas through the ostium is another way of expressing the ostial function. Drettner (1965b) found that the mean pressure needed to force the ostium open with saline solution was 800 mm H₂O in 30 cases with chronic maxillary sinusitis. Similar results were obtained by Zippel & Meier (1968) and Rantanen (1974).

Flottes et al. (1960) injected air into diseased sinuses and measured the pressure needed to force the ostium open. The pressure increase within the sinus was limited to 200 mm H₂O in order to avoid air embolism. They found that the pressure needed to force the ostium open exceeded 200 mm H₂O in 80 % of the cases in a series of chronic maxillary sinusitis. In 15 cases with chronic maxillary sinusitis, tested with the same method, Soubeyrand (1964) found that the pressure level forcing the ostium open exceeded 200 mm H₂O in all cases. Mann (1977) used an air pressure chamber when analysing the ostial resistance and found that the mean forcing pressure was 233 mm H₂O in 22 cases with chronic sinusitis.

The functional size of the ostium, expressed as the diameter in mm or the cross section area in mm², was estimated in healthy subjects by Aust & Drettner (1974a). They injected a constant air-flow of 1-6 litres per minute and by recording the pressure rise within the sinus they could calculate the equivalent ostial diameter with the aid of a diagram. As far as we know, this method has not been used in pathological sinuses.

The ostial airway resistance (R_o) can be estimated during nasal

breathing and expressed as $R_o = \frac{P_o}{\dot{V}_o}$, where P_o is the pressure difference between nose and sinus and $\dot{V}_o$ is the air-flow through the ostium. This method was first described for the naso-frontal duct by Andréasson et al. (1977) and has been tested on model experiments by Ivarsson et al. (1982) as well as on maxillary ostia in healthy subjects by Jannert et al. (1982).

No comparative studies have been performed in "diseased" sinuses as far as we know. In this study, the pressure transmission capacity, the airway resistance of the ostium and the equivalent ostial diameters, estimated during nasal breathing as well as with an artificial constant air-flow into the sinus, have been compared in three groups of patients (one with maxillary pain without any signs of disease; one with intrasinus cysts; and one with chronic sinusitis) with the following aims:

- to analyse the capacity of three different methods for clinical studies of the ostial function; and
- to evaluate the ostial function in three different groups of patients compared with normal subjects.

METHODS

According to Broms (1980) the nasal airway resistance (R_2) was obtained with anterior rhinomanometry during spontaneous breathing using the equation $R_2 = 10 \tan v_2 (\text{cm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1})$. A special cannula (Ivarsson et al., 1982) was used for pressure and air-flow recordings through the maxillary sinus. The function of the maxillary ostium was evaluated with three different techniques earlier described in detail by Ivarsson et al. (1982): simultaneous pressure recording in the maxillary sinus and the ipsilateral nasal cavity during nasal breathing (Method I); simultaneous recording of differential pressure between the sinus and the ipsilateral nasal cavity and air-flow through the ostium during nasal breathing (Method II); and recording of the pressure rise inside the sinus with an artificial air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ into the sinus (Method III). For details of the equipment, see Ivarsson et al. (1982).

Method I

The cannula of measurement makes an air-tight connection via a polyethylene catheter to a pressure transducer. The ipsilateral nasal cavity is sealed with "Leukoflex" tape and bypassed via a polyethylene catheter to an identical pressure transducer. The amplified pressure signals are recorded on an ink jet recorder and also recorded onto tape using an FM tape recorder for later pressure analysis on an x-y recorder.

Method II

The air-flow through the ostium is measured with a flow meter open to the atmosphere. The flow meter consists of a resistor and a differential pressure transducer and is connected to the cannula of measurement with a polyethylene catheter. The ipsilateral nasal cavity is sealed with "Leukoflex" tape and bypassed with two polyethylene catheters. One of these is connected to a pressure transducer for nasal pressure recording, while the other is connected to a pressure transducer which is also linked to the cannula of measurement. The nasal pressure, the pressure difference between the sinus and the ipsilateral nasal cavity as well as the air-flow through the ostium are recorded on an ink jet recorder and stored on an FM tape recorder for later analysis on an x-y recorder.

Method III

The same equipment is used as in method II. An air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ adjusted by means of a constant air-flow regulator is introduced into the sinus via the cannula of measurement. The air-flow is switched on and off by a valve and the differential pressure across the ostium is recorded on an ink jet recorder.

Calculation of equivalent ostial diameters

A diagram obtained from model experiments using known ostial diameters for a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method II) and $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ (Method III) has been used for estimating the equivalent ostial diameters. For the calculations the ostium is assumed to be circular with a length of 6 mm. For details, see Ivarsson et al. (1982).

TEST PERFORMANCE

The investigation started with a clinical examination of the nose and rhinopharynx. Thereafter, the patient underwent a roentgenological examination of the sinuses. All radiographs were judged by the same radiographer.

The canine fossa was punctured under local anaesthesia (1-2 cm³ carbocain 5 mg.ml⁻¹) and the position of the cannula was checked with a fiberscope (Olympus Ø 1.7 mm*) through which all sinuses were photographed. The measurements started in a sitting position with simultaneous pressure recording in the sinus and the ipsilateral nasal cavity (Method I). The pressure difference across the ostium and the air-flow through the ostium were then recorded during nasal breathing (Method II). Finally, the pressure rise within the sinus with the application of a constant artificial air-flow of 16.7 cm³.s⁻¹ was measured (Method III). This recording lasted <15 seconds, during which the patient was not allowed to breathe.

After 5 minutes in recumbency, all the tests were repeated in that position. Forced nasal inspiration (sniff-test) and Toynbee's manoeuvre were now included and measured (Method I). The cannula was then removed and the patients were investigated with rhinomanometry (Broms, 1980) in sitting and recumbent positions as well as after physical effort. Finally, blood samples were collected for sedimentation rate, leucocytes, erythrocytes, diff. count, total eosinophilic count, PRIST and nasal smears regarding eosinophilic leucocytes in order to get reliable diagnoses.

MATERIAL

The material consisted of 19 maxillary sinuses in 17 patients (13 ♀ and 4 ♂), aged 19-75 years ($\bar{x}$ = 43 years). The subjects were divided into 3 groups according to symptoms and radiographic, ultrasonic and sinoscopic findings.

The first group comprised 7 sinuses in 6 patients all of which complained of maxillary pain reminiscent of sinusitis. The duration

* ENF-P A1988, Olympus Corporation of America, 4 Nevada Drive, N.Y. 11042, U.S.A.

of symptoms varied between 2 and 15 years. All had earlier been treated once or several times with antibiotics because of suspected sinusitis without relief of the symptoms. Repeated radiographic examinations had always proved normal.

The second group comprised 6 maxillary sinuses in 6 patients with intrasinus cysts. Three of these patients had a slight feeling of oppression in one cheek and the remaining three had no symptoms but their cysts were discovered during a routine dental radiography examination.

The third group consisted of 6 maxillary sinuses in 5 patients with signs of chronic sinusitis. All had been treated with antibiotics and sinus lavage but had had persisting symptoms for at least 3 months. Antrostomy was planned in all cases.

RESULTS

Patients with maxillary pain

All patients showed normal findings in the clinical examination. In the rhinomanometry examinations all patients except one (MT) showed nasal airway resistance values within normal limits at rest as well as after physical effort.

The pressure relationship between the sinus and the ipsilateral nasal cavity (Method I) was 1:1 in all cases both in sitting and recumbent positions (Table I). The ostial resistances (R_o) and the equivalent ostial diameters in the sitting position (Method II) were $<25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ and $>2.5 \text{ mm}$, respectively, in 6 of the sinuses. In the remaining one (MT) R_o was found to be $50 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ and ϕ_o 2.1 mm with a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$. In the recumbent position there was a measurable increase of resistance in three ostia, corresponding to a decreasing equivalent ostial diameter, while in one case (MT) there was a decreasing resistance and increasing ostial diameter (MT $>2.5 \text{ mm}$) (Table I).

The equivalent ostial diameters estimated with an artificial air-flow (Method III) showed values of ostial diameters between 2.3 mm - 5.6 mm in the sitting position. When tested in recumbency, a reduction of the equivalent ostial diameters was found in all cases except one (MT). When comparing the ostial diameters in sitting and recumbent positions with healthy individuals

Table I.

Method I			Method II			Method III
P_s / P_n			Ostial resistance in $\text{mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$			ϕ mm for $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$
Cases	*	**	S	R	ϕ mm during inspiration	S R
UH	1:1	1:1	<25	<25	>2.5	5.6 4.5
BG	1:1	1:1	<25	<25	>2.5	3.1 2.9
KA sin	1:1	1:1	<25	<25	>2.5	2.8 2.5
MG	1:1	1:1	<25	50	>2.5	2.7 2.2
AD	1:1	1:1	<25	75	>2.5	2.3 2.1
MT	1:1	1:1	50	<25	2.1	2.5 2.7
KA dx	1:1	1:1	<25	300	>2.5	2.5 1.5

* S = Sitting

** R = Recumbent

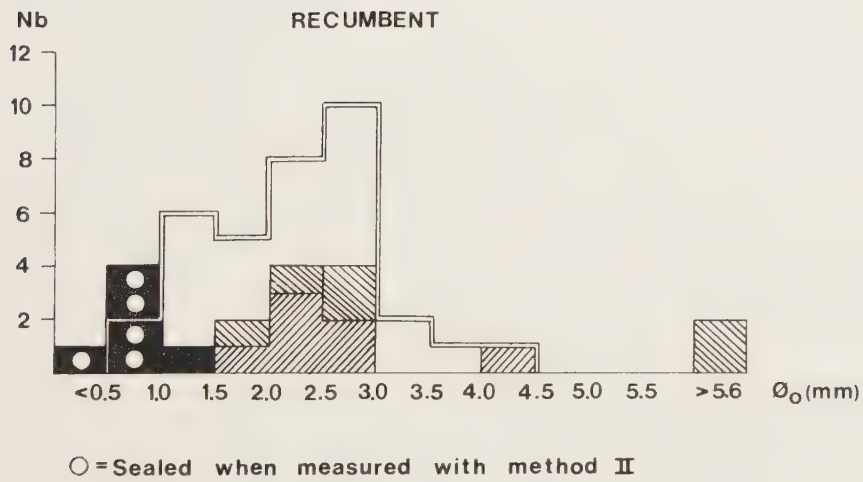
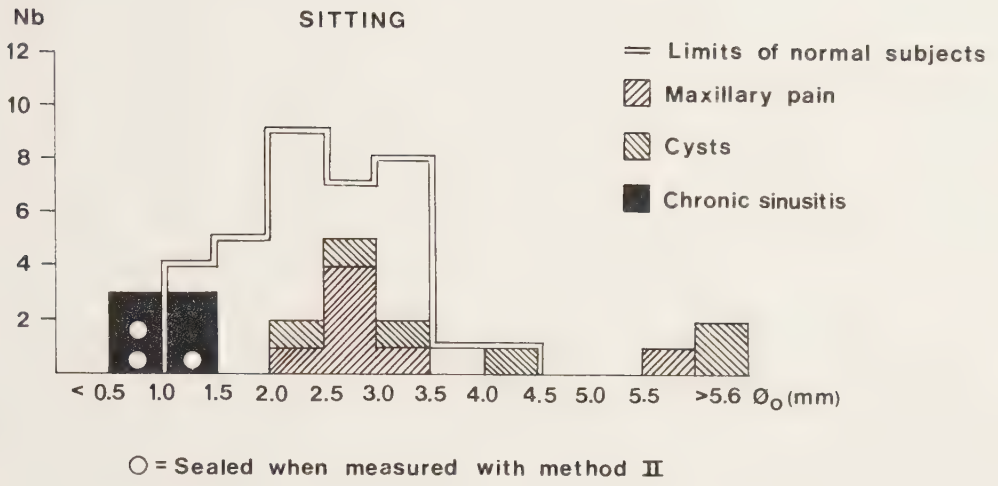


Fig. 1 Equivalent ostial diameters obtained with method III in comparison with healthy subjects.

(Jannert et al., 1982) no statistically significant difference was found ($p > 0.05$, Wilcoxon-Mann-Whitney's test) (Fig. 1).

The ostia were all patent when tested with Toynbee's manoeuvre and the sniff-test.

Patients with intrasinusal cysts

The clinical ENT-examination as well as the blood tests and nasal smears were quite normal in all cases. Radiography showed a cyst in 6 sinuses. From the sinoscopy examinations intrasinusal cysts were found in all sinuses located basally except in one (KO), where the cyst was found on the lateral wall. The results of the rhinomanometry tests gave values of nasal airway resistances within normal limits for all patients both at rest and after physical effort.

Table II shows the results of the ostial tests. The pressure relationship between the sinus and the ipsilateral nasal cavity (Method I) was 1:1 in all sinuses both in sitting and recumbent positions. With method II the ostial resistance at inspiration was $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$ in 4 sinuses in both sitting and recumbent positions. In 2 sinuses it was $40 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ and $75 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ in the sitting position and $175 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ and $115 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ in the recumbent position. The corresponding ostial diameters for method II were $> 2.5 \text{ mm}$ both in sitting and recumbent positions in 4 sinuses. In the remaining 2, the diameters were 2.2 mm (ER) and 1.9 mm (KO), respectively, and a reduction of the diameter was noticed in recumbency.

When the equivalent ostial diameters were estimated with method III, two were $> 5.6 \text{ mm}$ in both sitting and recumbent positions. In the remaining 4 sinuses the diameters varied between 2.1 mm and 4.1 mm and a reduction was seen in recumbency. Four of the ostia showed equivalent diameters within the limits of normal subjects (Jannert et al., 1982), while 2 showed larger equivalent diameters ($> 5.6 \text{ mm}$) ($p > 0.05$, Wilcoxon-Mann-Whitney's test) (Fig. 1). The ostia were all patent when tested with Toynbee's manoeuvre and the sniff-test.

Table II.

Method I			Method II			Method III
P_s / P_n			Ostial resistance in $\text{mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$			ϕ mm for $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$
Cases	*	**	S	R	ϕ mm during inspiration	S R
ÅK	1:1	1:1	<25	<25	>2.5 >2.5	>5.6 >5.6
GQ	1:1	1:1	<25	<25	>2.5 >2.5	>5.6 >5.6
EE	1:1	1:1	<25	<25	>2.5 >2.5	4.1 2.7
TJ	1:1	1:1	<25	<25	>2.5 >2.5	2.8 2.6
ER	1:1	1:1	40	175	2.2 1.5	3.1 2.4
KO	1:1	1:1	75	115	1.9 1.7	2.1 2.0

* S = Sitting

** R = Recumbent

Table III.

Rhinomanometry mm H ₂ O/1000 cm ³ . s ⁻¹ At rest At physical effort				Method I		Method II			Method III
Cases	S	R	S	P _s / P _n		Ostial resistance in mm H ₂ O/1000 cm ³ . s ⁻¹	Ø during inspiration	Ø mm for 16.7 cm ³ . s ⁻¹	
MJ [*]	12	79	53	1:1	1:1	<25	>2.5	1.5	1.2
VH	71	74	34	1:1	-	<25	>2.5	0.9	0.6
BE dx [*]	60	87	41	1:1	1:1	300	1.3	1.1	0.9
LB	185	185	53	0.75:1	-	-	-	1.1	0.6
SA	29	78	12	-	-	-	-	0.8	0.6
BE sin	>1000	>1000	75	-	-	-	-	0.6	<0.5

S = Sitting

R = Recumbent

* Both cases showed positive sniff-test and Toynbee's manoeuvre.

Patients with chronic sinusitis

The clinical ENT-examination showed normal conditions in all cases. Radiography showed a local mucosal swelling in one case and in the remaining 5 cases general mucosal swelling. Sinoscopy showed purulent secretion and mucosal swelling in one sinus and different degrees of mucosal swelling in the remaining sinuses.

Rhinomanometry showed pathological airway resistance values of the ipsilateral nasal cavity in 2 cases (LB and BE sin) both in sitting and recumbent positions, while the remaining results were within normal limits. After physical effort all showed normal rhinomanometry (Table III). Three sinuses (MJ, VH and BE dx) showed a pressure relationship (Method I) of 1:1 in the sitting position. In one of them (VH) the ostium was not patent in recumbency. In another sinus (LB) the pressure relationship was 0.75:1 in the sitting position, which means lower pressure changes in the sinus compared with the ipsilateral cavity. A hysteresis was found in this case as an indication of a time-lag in the pressure transmission between the nasal cavity and the sinus. In the recumbent position the ostium was closed and in the remaining 2 patients the ostia were closed even in the sitting position.

With the pressure-flow technique during nasal breathing (Method II) 2 cases (MJ and VH) showed ostial resistance in the sitting position $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ at a flow of $2.0 \text{ cm}^3 \cdot \text{s}^{-1}$, which means equivalent ostial diameters $> 2.5 \text{ mm}$. One patient (MJ) showed no measurable changes in recumbency, while the other (VH) closed the ostium in the recumbent position. In a third case (BE dx) the ostial resistance was $300 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ and the corresponding equivalent diameter was 1.3 mm . In recumbency this ostium closed. In the 3 remaining cases no pressure-flow recordings at all were possible during nasal breathing.

With an artificial constant air-flow applied to the sinus (Method III) the equivalent ostial diameter could be calculated in all cases in the sitting position. A constant pressure difference between the sinus and the ipsilateral cavity was immediately created in three of the cases (MJ, VH and BE dx) (Fig. 2 A,B,C). In the remaining 3 sinuses (Fig. 2 D,E,F) the ostium was forced open. A gradual decrease in the pressure recorded took place within about 10 seconds then a steady state was obtained. The latter value

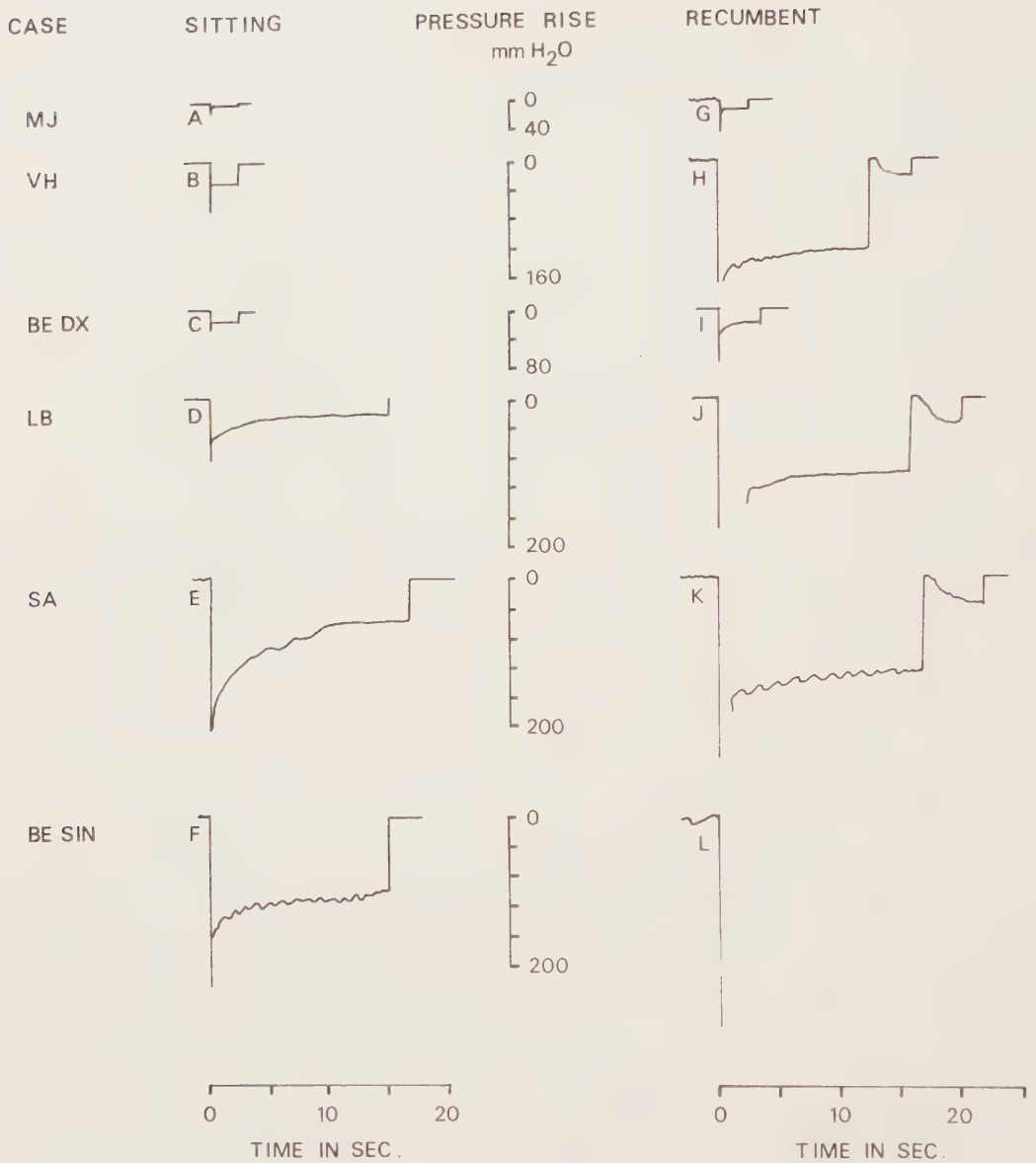


Fig. 2 Recording of the intrasinus pressure rise with a constant artificial air-flow of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ into the sinus (Method III).

was used to estimate the equivalent diameters of the ostium.

The equivalent ostial diameters could be estimated in all cases in the sitting position (range 0.6 mm-1.5 mm). In recumbency there was a reduction of the ostial size in all cases. In one case (BE sin) (Fig. 2 L) the measurements had to be interrupted before a steady state was obtained as the patient complained of discomfort. The equivalent ostial diameters in the cases with chronic sinusitis (Fig. 1) were statistically separated from the values of normal subjects ($p < 0.01$, Wilcoxon-Mann-Whitney's test) (Jannert et al., 1982). Toynbee's manoeuvre and the sniff-test in the recumbent position were only positive in 2 cases (BE dx and MJ). A relationship was found between the small ostial size and increased resistance of the ipsilateral nasal cavity in 2 patients (LB and BE sin) with chronic sinusitis.

DISCUSSION

The patients were divided into three groups due to signs and symptoms in order to obtain one group where an impaired ostial function could be expected (chronic sinusitis). The groups with maxillary pain and intrasinus cysts were selected as no analysis of the ostial function in such cases has been published as far as we know.

With the simultaneous pressure recording technique the patients could be separated into three functional groups: one with a pressure relationship between the sinus and the ipsilateral nasal cavity of 1:1 in both sitting and recumbent positions and without any signs of hysteresis; one group with a pressure relationship separated from 1:1 and hysteresis; and one group with no pressure transmission at all. All patients with maxillary pain or cysts (Table I and II) showed a pressure relationship of 1:1 in both sitting and recumbent positions and this corresponds to the findings in healthy individuals (Jannert et al., 1982). Thus, in our material, maxillary pain reminding of sinusitis occurred without any measurable impaired ostial function. The ethiology of the intrasinus cysts cannot be explained by this study as our tests only mirror the state of the ostial function at the moment of investigation. In patients with chronic sinusitis (Table III) only three showed a pressure relationship of 1:1 in sitting

position and two in recumbent position. One case (LB) (Table III) showed a reduction in pressure relationship (0.75:1) as well as a time-lag of the pressure transmitted, seen as a hysteresis on the x-y recorder. No such findings were noticed in the normal subjects (Jannert et al., 1982). In model experiments hysteresis, as a sign of a time-lag, was seen when the ostial diameter was ≤ 0.60 mm at a sinus volume of 25 cm^3 (Ivarsson et al., 1982). Time-lag as a sign of an impaired ostial function was also reported by Proetz (1932) and Drettner (1965a). With simultaneous pressure recording in sinus and nasal cavities, the ostia can only be qualitatively judged as patent, partially obstructed (LB) or non-patent and this is in accordance with Drettner (1965a), Aust & Drettner (1974b) and Kortekangas & Rantanen (1976).

With pressure-flow recording during nasal breathing the ostia can also be separated into three functional groups: one with good function, which means an airway resistance $< 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$ corresponding to an equivalent diameter > 2.5 mm; another with an airway resistance $> 25 \text{ mm H}_2\text{O}/1000 \text{ cm}^3 \cdot \text{s}^{-1}$, which means an equivalent diameter < 2.5 mm; and a third with no measurable air-flow at all through the ostium during nasal breathing. In the present material 12 ostia showed a good function, 4 showed a measurable resistance and 3 (Table III) were obstructed during nasal breathing in the sitting position. All cases with maxillary pain or intrasinus cysts showed good function or measurable ostial resistance, which corresponds to the figures obtained in healthy individuals (Jannert et al., 1982). This method permits a quantitative grading of the ostial function during nasal breathing. A good correlation exists between method I and method II as both are performed during nasal breathing. Three of the 6 sinuses with chronic sinusitis showed patent ostia when measured with both method I and method II in the sitting position. Drettner (1965a) found all ostia closed in cases with chronic sinusitis when using method I.

With a constant artificial air-flow into the sinus the patients could also be separated into three groups: one with equivalent ostial diameters > 5.6 mm; a second with equivalent ostial diameters between $0.5 \text{ mm} - 5.6 \text{ mm}$; and a third with equivalent ostial diameters $< 0.5 \text{ mm}$. With this method (III) the equivalent ostial diameters could be estimated in all cases in the sitting position

and in all cases except one (BE sin) in recumbency. In this case the air-flow had to be cut off as the patient complained of discomfort. Two cases (Table II, Fig. 1) showed equivalent ostial diameters >5.6 mm in sitting and recumbent positions. In these cases no accessory ostia were seen with the fiberscope. In the remaining cases with maxillary pain or cysts (Table II, Fig. 1) the values of the equivalent ostial diameters were within the limits of normal subjects (Jannert et al., 1982). However, all cases with chronic maxillary sinusitis showed small equivalent ostial diameters (0.6 mm - 1.5 mm) in sitting as well as in recumbent positions (Table III, Fig. 1). The pressure level needed to force a closed ostium open (Fig. 2 H,J,K,L) could not be accurately recorded as pressure levels exceeding 220 mm H₂O are not measurable with the equipment used. The latter is adapted to estimate the equivalent ostial diameters requiring a high pressure sensitivity, which cannot be combined with a requirement to record high pressure levels. This means that no direct comparison can be made with the results published by Mann (1977) who found a mean forcing pressure level of 233 mm H₂O in chronic maxillary sinusitis but it is worth mentioning that no ostia were totally obliterated from an anatomical point of view. As can be seen in Fig. 2 (D,E,F,H,I,J,K) there was a gradual decrease in the pressure rise within the sinus until a steady state was obtained after about 10 seconds. However, these values do not mirror the "true functional state" of the ostium as the mucosa is decongested by the increased intrasinus pressure. In Fig. 2 (H,J,K) a pressure rise is recorded after the air-flow has been cut off, reflecting the elastic effects on the decompressed mucosa in the closed cavity. In the remaining three cases with chronic sinusitis the ostia (MJ, VH, BE dx) were patent in the sitting position and one (MJ) in the recumbent position and thus measurable both with method II and method III (Fig. 2 A,B,C,G). As can be seen from Table III the equivalent ostial diameters estimated with method II were larger than those estimated with method III. The pressure differences created with method III were small (Fig. 2 A,B,C,G) and immediately obtained in spite of a flow level of $16.7 \text{ cm}^3 \cdot \text{s}^{-1}$ which is 8 times higher than that used in method II ($2.0 \text{ cm}^3 \cdot \text{s}^{-1}$). The results obtained indicate that the ostia were patent in these cases. The combination of a low pressure difference between the sinus and the ipsilateral nasal cavity and a large flow of air

through the ostium might explain the small ostial sizes recorded with method III, probably due to the Bernouille effect on the swollen ostial mucosa.

In all cases except one (MT) (Table I) the ostial size decreased or was unchanged (AK, GQ) (Table II) in recumbency when measured with method III. This is in accordance with the findings in healthy individuals (Aust & Drettner, 1975; Jannert et al., 1982). The mean reduction of the equivalent ostial diameters of the present subjects in the recumbent position was 0.48 mm compared with 0.24 mm in normal individuals (Jannert et al., 1982). Identical effects of body position were found in 7 cases measurable with method II. However, in one case (MT) both methods showed an increased ostial size in recumbency (Table I). A possible explanation for this may be that a piece of floppy mucosa or a polype in the ostium was moved by changing the position of the patient and thereby affecting the ostial size in this unexpected way.

As all patients in the groups of maxillary pain and cysts showed normal ostial function and as all rhinomanometric values except one were within normal limits (Broms, 1980), no values of the rhinomanometric tests have been given in Table I and Table II. In the group of chronic sinusitis two cases (LB and BE sin) showed pathological nasal resistance both in sitting and recumbent positions but normal values after physical effort (Table III). These patients showed closed ostia when measured with method II and the smallest equivalent ostial diameters in the whole series when measured with method III. These findings might be explained by an intranasal mucosal swelling confirmed in normal individuals (Jannert et al., 1982).

In conclusion, three different ostial patency test methods all integrated into one single piece of equipment which offers valuable possibilities for dynamic as well as static evaluation of the ostial function, have been described. With simultaneous pressure recording in the sinus and the ipsilateral nasal cavity, no quantitative evaluation of the ostial function was possible. When using the pressure-flow technique the ostial function can be evaluated under physiological conditions by estimating the ostial resistance and the equivalent ostial diameter. With an artificial constant air-flow into the sinus, the closed ostium is forced open

due to a pressure load on the mucosal lining. The numerical values of the ostial diameters obtained in these cases do not mirror the true functional state of the ostia. Thus, out of the three methods, the pressure-flow technique seems to be the most physiological one for evaluation of the ostial function, e.g. for selection of patients suitable for endonasal antrostomy.

ZUSAMMENFASSUNG

Die ostiale Funktion, gemessen als Drucktransmissionskapazität ostialer Atemluftwegwiderstand, ostiale Grösse bei nasaler Atmung und Ostiengrösse bei konstantem artifizielltem Luftstrom von 1 Liter pro Minute wurden in drei Patientengruppen verglichen. Die erste Gruppe bestand aus 7 Nebenhöhlen bei 6 Patienten mit Gesichtsschmerzen, aber ohne Anzeichen auf Sinuit; die zweite Gruppe aus 6 Nebenhöhlen bei 6 Patienten mit intramaxillaren Zysten; und die dritte Gruppe aus 6 Nebenhöhlen bei 5 Patienten mit chronischem maxillarem Sinuit. Bei den ersten und zweiten Gruppen wurde keine Einschränkung der ostialen Funktion entdeckt. In der dritten Gruppe wurde ein erhöhter Atemluftwegwiderstand und kleine ostiale Grössen sowohl in sitzender als auch in liegender Stellung gefunden, aber die meisten Ostien waren bei Nasenatmung geschlossen. Mit Druckmessungstechnik kann das Ostium als offen, nicht offen oder teilweise verstopft beschrieben werden; eine weitere Graduierung kann nicht gemacht werden. Mit Druck-Strömungs-Technik kann die ostiale Funktion unter "physiologischen Bedingungen" ausgewertet werden, wenn das Ostium offen ist. Mit einem konstanten artifiziellen Luftstrom kann die ostiale Grösse auch bei nicht offenen Ostien geschätzt werden. Die erhaltenen Diameter reflektieren aber nicht den wirklichen funktionellen Status des Ostiums.

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SUPPLEMENT 389

ULTRASONIC EXAMINATION OF THE PARANASAL SINUSES

by

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FOREWORD

In ENT-practice patients with sinusitis make up a substantial part of the clientele. It is of importance to discriminate between sinusitis and rhinitis as the treatment differs considerably. The diagnostic methods hitherto used are clinical examination, radiography, diagnostic sinusal aspiration or lavage. During the last decade ultrasonic examinations have been the object of increasing interest. However, most earlier equipment used was not adapted for this special purpose and was technically complicated. Therefore, a specially constructed piece of equipment and three different display systems have been developed. Model experiments have been performed in order to evaluate the best display technique (paper I) as well as direct comparisons (paper II) between ultrasonic examination, radiography and invasive control in clinical cases.

Magnus Jannert

Lars Andréasson

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NEW ULTRASONIC EQUIPMENT FOR DIAGNOSTIC SCREENING OF PARANASAL SINUSES - AN EXPERIMENTAL STUDY

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Abstract. Simplified ultrasonic equipment for diagnostic screening of the paranasal sinuses using three different display units - oscilloscope (OSC), light emitting diodes (LED), and gas discharge (GD) displays - has been tested and compared in model experiments as well as on autopsy specimens. The different display units showed the same capacity in separating air from fluid contents. A statistically significant difference was found in the minimum amount of saline solution which could be detected in human sinuses with the OSC-display (mean 1.6 ml) compared with the GD-display (mean 2.1 ml) and with the LED-display (mean 3.1 ml). Artificial mucosal swelling > 3 mm was detected with the OSC-display, while "mucosal swelling" < 8 mm was not detected with the other display units. Artificial cysts were detected and separated from saline solution with the OSC-display in model as well as in human experiments, which was not possible with the use of the other display units. The study indicates that the OSC-display unit may be the most valuable display technique for both scientific purposes and in clinical practice in separating different pathological conditions. The other simplified and less complicated display units (LED and GD) seem, however, to be useful for routine screening purposes.

Ultrasound as a diagnostic tool in medical practice has received increasing attention during the last four decades. Dussik (1942) made the first attempts to use ultrasonography in diagnosing neurological disorders and Keidel (1947) proposed the possibility of using ultrasound in the examination of the paranasal sinuses. The first clinical trials on the applicability of ultrasound in diagnosis of maxillary sinusitis were published by Mann in 1977.

In experiments on human and rabbit maxillary sinuses Ginzburg (1961) found that foreign bodies and water in sinuses could be detected with ultrasound examination. In 1968 Gilbricht & Heidelberg performed experiments, e.g. during autopsies and in vivo on maxillary sinuses in patients. They described the typical echoes in an air-filled sinus as well as in a sinus filled with water. These findings were confirmed by Kitamura et al. (1969) who studied the different echograms for air and water in a maxillary sinus model. They also described multiple echoes seen when the sinus cavity was filled with tumour tissue. Using bone models, Revonta (1980) found that a water level of 2 mm could be detected. In a group of 10 maxillary sinuses with minor mucosal swelling saline was added in steps of 0.5 ml into the sinus until the back wall echo was clearly detected; the amount needed was 1 to 3 ml.

So far the use of diagnostic ultrasonography for paranasal sinus diseases has only become routine in a few centres, probably due to the lack of equipment well adapted for this special purpose. Almost all earlier published studies have been performed with technically complicated equipment, basically designed for cardiological or obstetrical purposes.

Therefore, a piece of simplified mobile ultrasound equipment using a quasi-logarithmic amplifier (Holmer & Lindström, 1978) combined with an oscilloscope was developed at Malmö General Hospital, Malmö, and Teltec, Lund, Sweden (Jannert et al., 1981a,b). In an attempt to find a reasonably inexpensive but still reliable display unit compared with an oscilloscope (OSC) display a row of light emitting diodes (LED) (Jannert et al., 1980) as well as a gas discharge (GD) display (Holmer et al., 1981) were used.

The present study was performed in order to evaluate the capacity of the three different display techniques on paranasal sinus models constructed of plexiglass as well as on bone models

and maxillary sinuses from autopsy specimens. The special aims have been:

- to judge the degree of bone thickness which can be penetrated by ultrasound pulses;
- to evaluate the smallest detectable amount of saline solution in adult maxillary sinuses;
- to evaluate the shortest distance between the frontal wall and the back wall of a sinus which can be separated by ultrasound; and
- to evaluate the origin of the double echo often seen in cases with intrasinus cysts by studying the pattern of ultrasound echoes from convex and concave surfaces.

METHODS

The generation and detection of ultrasound echo signals depend on the piezo-electric effect (Curie & Curie, 1880). Material with this property can convert mechanical pressure into electrical charges and vice versa. This is done by a so called transducer which both produce and detect short pulses of ultrasound. In all the experiments described below three transducers, trade-mark Dapco^{*}, have been used: one with a diameter of 10 mm and a frequency of 3.5 MHz; and two with diameters of 13 mm and frequencies of 2.25 MHz and 3.5 MHz, respectively. The ultrasound pulses are reflected when reaching a boundary between materials with different acoustic impedances. The acoustic impedance can be calculated from the equations: $Z = v \cdot \rho$ where Z means impedance ($\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$), v means sound velocity ($\text{m} \cdot \text{s}^{-1}$) and ρ means density ($\text{kg} \cdot \text{m}^{-3}$).

The ultrasonic pulse echo method is used for diagnostic purposes with frequencies above 1 MHz. For detailed information about the basic physics of ultrasound, see Appendix, and Wells (1969), Holmer & Lindström (1978) and Woodcock (1979).

Basically, a piece of ultrasound equipment consists of a transmitter, a receiver and a display. In the three different

^{*} Dapco Industries, Inc. Ridgefield, Conn. 06877 U.S.A.

pieces of equipment used, a receiver of a new type was constructed on the principle that small signals will get large amplification and large signal small amplification. This compression technique of a logarithmic type makes it possible to display echoes of a large variation, e.g. from maxillary and frontal sinuses.

The quasi-logarithmic amplifier

It is well known that the conventional time gain control (TGC)-circuit can barely be adjusted in such a way that it is possible to make correct compensation for attenuation in all situations. To circumvent this problem an amplifier-detector combination was constructed which has a dynamic range of almost 100 dB allowing the display of input signals in the range 30 μ V to 3 V. Since the amplitude mode (A-mode) has a visual display range of < 30 dB, the amplifier circuit must introduce compression of the signals by means of logarithmic amplification. The technique is illustrated in Fig. 1. A quasi-logarithmic function can be generated by using many amplifier- and detector stages in cascade. From each of these stages the isolated demodulated signal can be added. Ground loop and interference problems are almost totally circumvented by the use of opto-couplers. For instance, if the first stage is saturated, the second and the third stages may also be saturated but the last stage works within its linear range, then by summing the signals after each stage a quasi-logarithmic function has been reached. The amplifier has the amplification characteristic shown in Fig.2. Using this technique the total echo signal range will be shown on the A-mode display without using a gain control. This technique provides a very convenient and easily handled system.

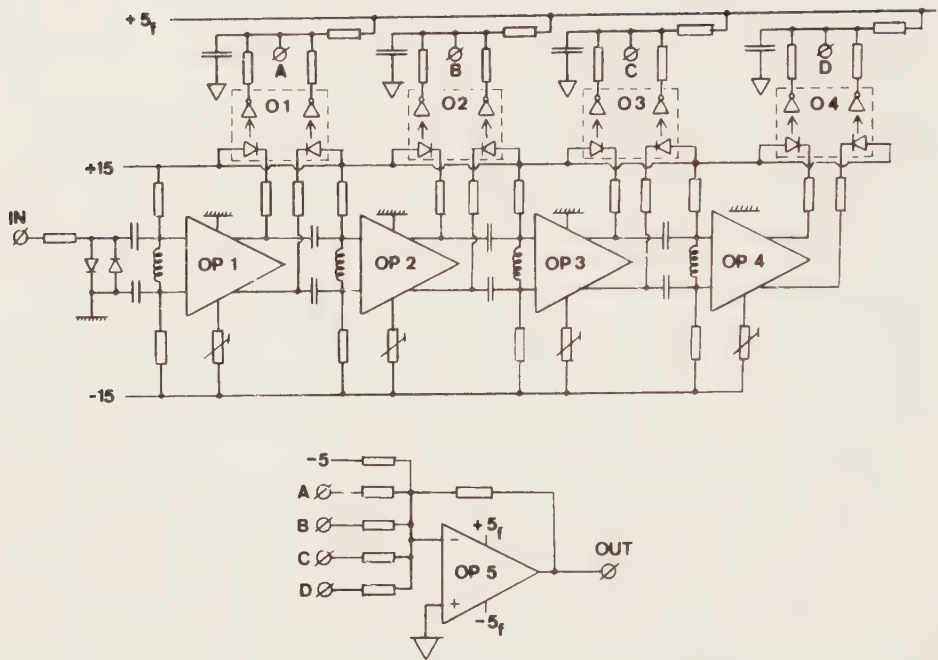


Fig. 1. The quasi-logarithmic amplifier constructed with isolated detectors after each stage.

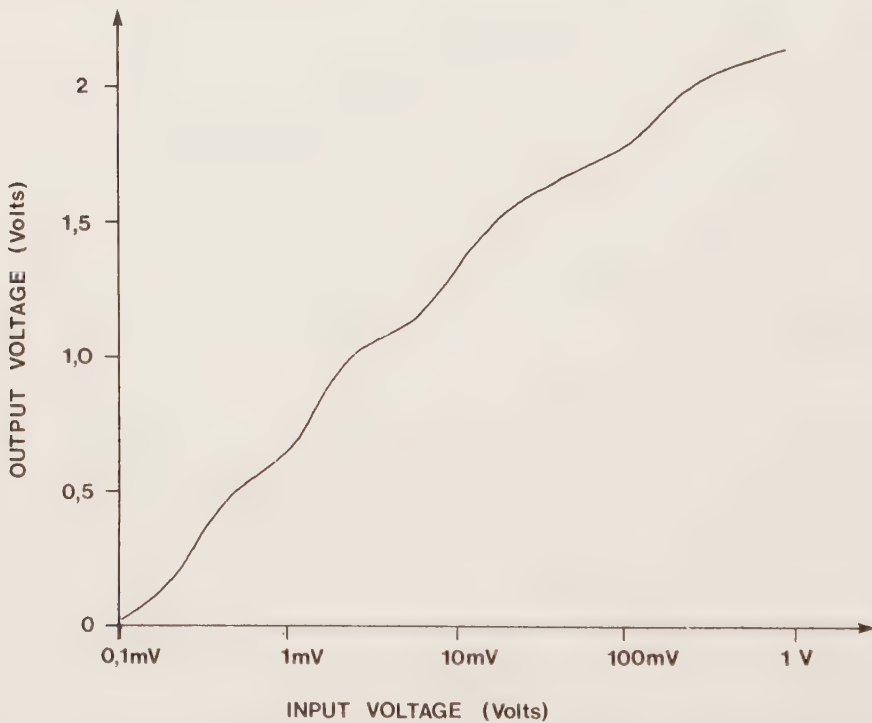


Fig. 2. Output voltage as function of the input voltage for the entire amplifier.

A. Equipment using an ordinary oscilloscope (OSC) display

A pulsed ultrasonic system, mainly consisting of a clock, a transmitter, a quasi-logarithmic amplifier, an ordinary oscilloscope, and a built-in digital memory, is illustrated in Fig. 3a. The clock circuit determines the ultrasound pulse repetition rate which has a frequency of about 1.2 kHz. The clock activates the transmitter using very fast radar thyristors in order to provide a short pulse for the transducer. It also synchronizes and controls the analogue to digital converter (A/D-converter). The received echo signals are sampled every 330 ns and stored in the memory and then fed via the D/A-converter digital to analogue converter to the oscilloscope. Instead of storing new data the old data can be read just by selecting the store mode. It is thereby possible to display the same stored A-mode picture for examination as long as necessary. This facility makes it possible to study very small changes in the echo amplitude, e.g. marginal mucosal swelling.

B. Equipment with a single row of light emitting diodes (LED) display

For screening tests a very simple display system was developed. A block diagram of this system is shown in Fig. 3b. The same quasi-logarithmic amplifier is used and the clock controls both the transmitter circuit and the "logic". The latter connects the light emitting diodes one at a time directly to the amplified and rectified ultrasound signal. This instrument has no internal memory. To get sufficient light from the diodes the pulse-repetition rate as well as the current-pulse through the light emitting diodes must be as high as possible. The LED-instrument allows two alternative scales, where each diode either corresponds to 1 or 2 mm of soft human tissue, assuming a sound velocity of 1540 m.s^{-1} .

C. Equipment with a gas discharge (GD) display

In order to obtain better resolution than with the LED-display, the number of rows must be increased and the intensity modulation must be left. For steady binary modulation of a gas discharge display with 7 rows and 111 columns (Fig. 3c) is used to display an ordinary A-mode picture. Continuous registration of the

amplitude of the echo is therefore divided into 6 different levels. The sampling rate of the echo amplitude is again chosen to correspond to either 1 or 2 mm in soft human tissue. However, the GD-display can only be up-dated at a maximum speed of 7 kHz. Hence, the ultrasound echo signal must first be stored in a memory with high frequency before the digitalized signal can be read out at a low speed on the display. The memory is also used for "freezing" the A-mode picture.

A simplified block diagram of the pulse echo system with memory in a self-scan display developed by our group is also shown in Fig. 3c. The equipment consists mainly of 6 blocks. The clock activates the transmitter circuit. The ultrasound transducer transmits a short ultrasound pulse and the received echo is converted to an electrical signal by the same transducer. The small echo signals are then amplified by the quasi-logarithmic amplifier. The rectified signal is digitalized in an A/D-converter consisting of 6 different comparators and their digital values are stored in the memory. The digital values are clocked into the memory at a frequency of 0.77 or 1.54 MHz, corresponding to a thickness of 1 or 2 mm in human tissue assuming a sound velocity of $1\,540\text{ m}\cdot\text{s}^{-1}$. The stored values are then read out at a frequency of 7 kHz. After each complete cycle of storing and read-out, the transmitter is again activated and therefore the pulse repetition rate of this equipment is about 60 Hz.

Experimental models

Three different experimental set-up modes have been used: one on plexiglass models (I); a second on bone models (II); and a third on human maxillary sinuses (III). In all experiments the display units have been used in the following order: OSC-, LED- and GD-displays. All display units have been photographed with a Polaroid camera with an exposure time of 1/30 second when using the OSC- and the GD-display units and 3 seconds when using the LED-display unit.

I. Plexiglass models. Two different plexiglass boxes with inner measures of 10 mm and 50 mm, respectively, were used as well as a cylinder with a diameter of 50 mm. The wall of the box nearest to the transducer is called the "frontal wall" and the opposite

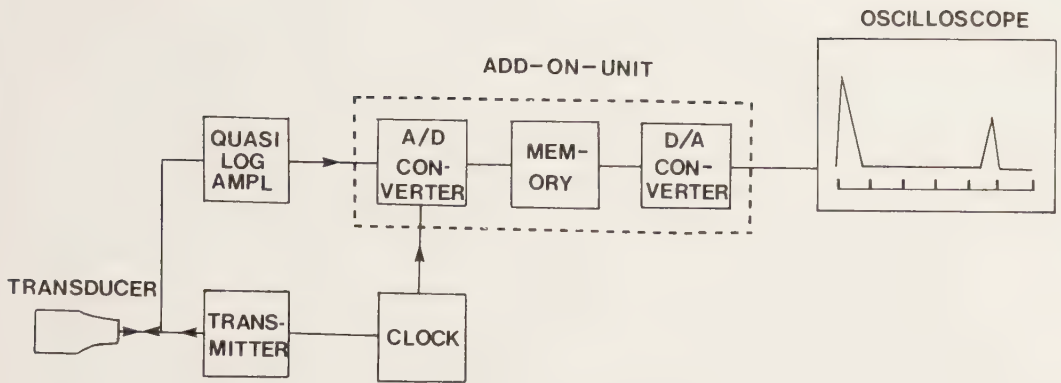


Fig. 3a. Block diagram of the equipment using an oscilloscope (OSC) as the display unit.

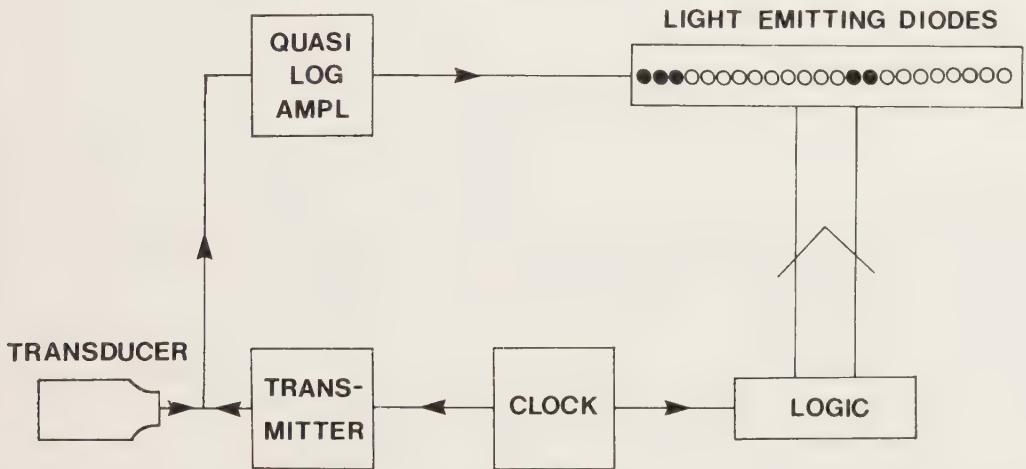


Fig. 3b. Block diagram of the equipment with a single row of light emitting diodes (LED) as the display unit.

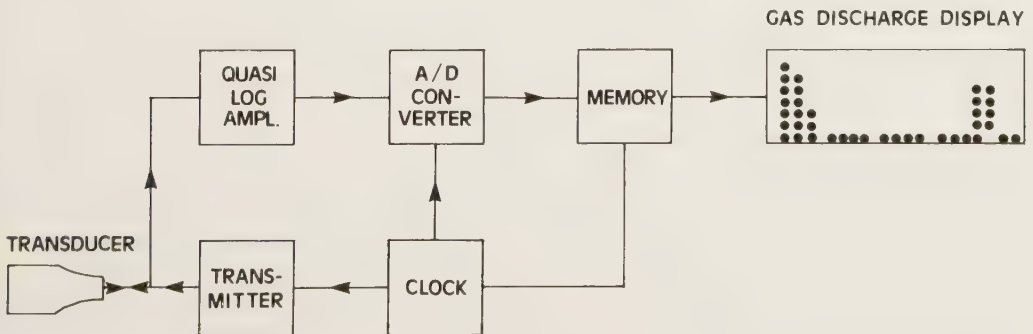


Fig. 3c. Block diagram of the equipment with a gas discharge (GD) display.

one the "back wall". The thickness of the box material was 4 mm and that of the cylinder 1 mm. The boxes were first tested with ultrasound when containing air. Then, the smallest detectable amount of saline was measured as well as the shortest distance between the frontal and back wall which could be separated with the different systems. This was done with a piece of plexiglass which could be moved within the cavity of the box. The plexiglass boxes were also tested when filled with "Aquasonic" gel* before and after the gel was mixed with air.

In order to simulate mucosal swelling the frontal wall of the plexiglass box was covered with the gel and the relationship between gel and air as well as the relationship between gel and saline solution was studied. This experiment was repeated with the back wall of the box covered with gel (5 mm) and the box filled with saline. An india-rubber balloon (artificial cyst, 25 mm diameter) filled with saline was placed into the large box. It was first examined with the balloon placed against the frontal wall. Hereafter the volume of the balloon was increased until the box was completely filled. This experiment was repeated when a small amount of saline had been added to the box. The test procedures were then performed on the cylinder. Finally, an india-rubber hemisphere with a diameter of 64 mm was placed hanging in a box filled with saline solution. The ultrasound echo was photographed when reflected off the convex as well as the concave surface.

II. Bone models. In the second part of the experiments excavated marrow bones were used with approximate inner diameters of 20 mm and 50 mm. The thickness of the bone walls varied between 5 mm to 16 mm. The experiments mentioned above were also performed in applicable parts on the bone models.

III. Human maxillary sinuses. In the third part of the investigation, 10 maxillary sinuses in 5 adults were used at autopsy to study the smallest amount of saline which could be detected on the different display units. They were examined within 12 hours

* Parker Laboratories, Inc., Orange, N.J. 07050 U.S.A.

after death in order to diminish the risk of post mortal changes of the intrasinusal mucosa.

The experiments started with an ultrasound examination of the maxillary sinuses with the body in a horizontal position, after which the sinuses were examined by sinoscopy via the middle nasal meatus in order to detect any pathological changes. The experiment was then repeated in a vertical position. One ml of saline was injected into the sinus, after which ultrasonographic examination was carried out. The injection of saline was repeated step-wise by adding 1 ml until the ultrasound examination showed a distinct echo from the back wall. Then, the sinus was examined with the head tilted backwards.

In two maxillary sinuses an inflatable balloon was introduced through the middle meatus after sinoscopy. The sinuses were examined when the balloon was filled with 2, 5 and 10 ml saline, respectively, in order to simulate intrasinusal cysts.

RESULTS

In all experiments identical echoes were found with the different transducer diameters and frequencies tested (10 mm, 3.5 MHz; 13 mm, 2.25 MHz; and 13 mm, 3.5 MHz).

I. Plexiglass model

Examination of the air-filled box showed total reflection of the ultrasound pulse with all three display units. The transducer pulse was, however, intermingled with small repetition echoes (Fig. 4:1). When saline solution was added a back wall echo (BWE) was distinctly indicated on all display units at a saline level of 2 mm (Fig. 4:2). The shortest separable distance between the frontal and back wall was about 5 mm when using the OSC and about 10 mm and 9 mm when using the LED- and GD-displays, respectively. When the plexiglass box was filled with gel a distinct BWE was shown on all three display units. This echo disappeared when the gel was mixed with air.

A simulated swelling (gel), up to 3 mm or more, was detected on the OSC-display as an air/mucosa echo (AME), while the other two display units could not distinguish between "mucosal swelling" and repetition echoes if the thickness of the simulated mucosal

swelling was < 8 mm (Fig. 4:3). The AME as well as the BWE were detected with the OSC-display when saline was added to the box. When more saline was poured into the box, reaching the upper level of the simulated mucosa, the AME disappeared. When the back wall of the box (50 mm away) was covered with gel and saline was added a BWE consisting of two components was found on the OSC-display, while the LED- and GD-displays showed wide echoes (Fig. 4:4).

When the india-rubber balloon was placed against the frontal wall of the box (inner measure 50 mm), a double choe (DE) was seen on the OSC-display, while the other displays showed single echoes (BWE) (Fig. 5:1). When the size of the balloon was increased the DE on the OSC-display moved towards the back wall of the box and was finally seen as a BWE. When the balloon was placed in the box and saline was added the back wall of the balloon was indicated as a DE on the OSC-display, while the back wall of the box was seen as a BWE. With the other display units no DE was found but two BWEs indicating the back walls of the balloon and the box (Fig. 5:2).

The results obtained with the cylindrical model corresponded to those related above, while a DE was found on the OSC-display when the model was filled with saline.

A DE was seen both with the OSC- and the GD-displays, while the LED-display showed a BWE when an india-rubber hemisphere was placed hanging in saline solution and the concave surface was examined (Fig. 5:3). When the convex surface was examined a single echo (BWE) was detected with all three display units (Fig. 5:4).

II. Bone models

An excavated marrow bone with a wall thickness up to 16 mm was penetrated by the ultrasound pulse. A BWE was distinctly seen on the OSC- and the GD-displays when saline was added (up to a level of 3 mm) but the level had to be at least 5 mm until it was positively detected with the LED-display. The shortest distance which could be separated was about 3 mm with the OSC- and the GD-displays and about 5 mm with the LED-display. In the remaining tests the results were identical to those obtained with the plexiglass models.

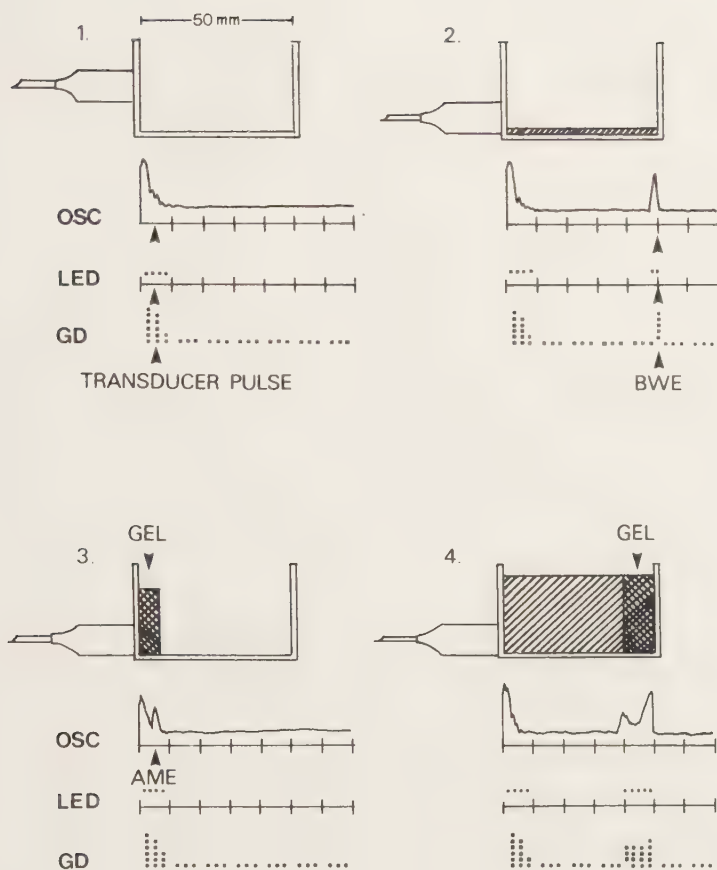


Fig. 4. Different echo patterns obtained in the model experiments. For explanation, see text.

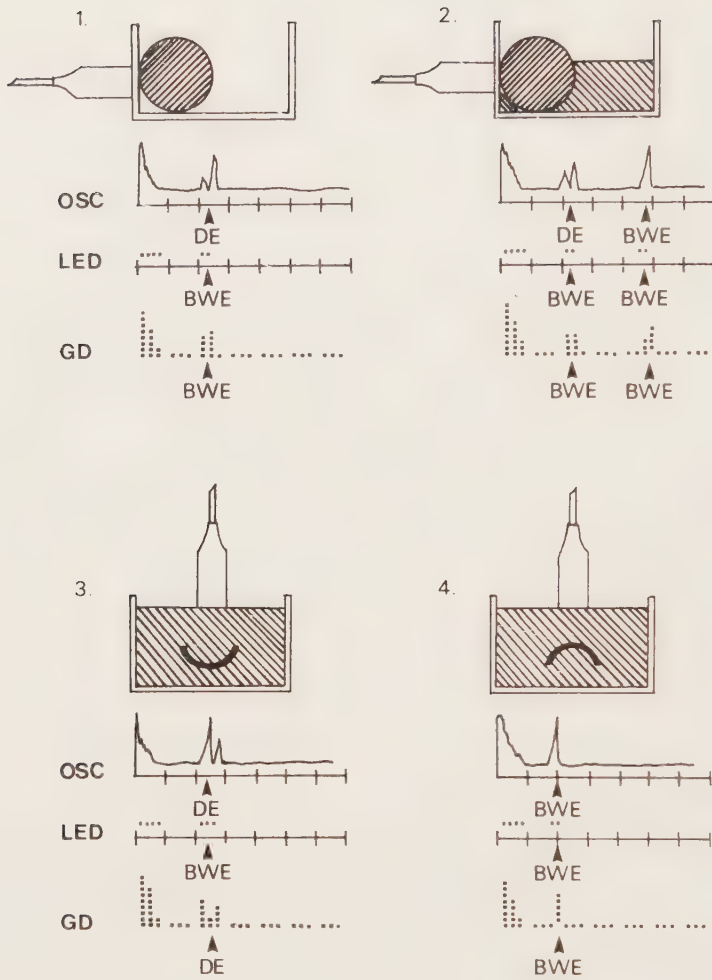


Fig. 5. Different echo patterns obtained in the model experiments. For explanation, see text.

III. Human maxillary sinuses

Table I shows the amount of fluid in ml needed to obtain a distinct BWE with the different display units. A statistically significant difference ($p < 0.01^*$) was found between the OSC-display ($\bar{x}=1.60$ ml; $SD \pm 0.70$) and the LED-display ($\bar{x}=3.10$ ml; $SD \pm 1.37$) and also between the OSC- and GD-displays ($p < 0.05$). When comparing the GD- ($\bar{x}=2.10$; $SD \pm 1.10$) and LED-displays no statistically significant difference was found ($p > 0.05$) in their capacity to detect fluid.

When the head was tilted backwards the BWE disappeared in all cases but it returned when the head was placed in an upright position. The sinuses could not be completely filled with saline because of leakage through the ostium or the trocar introduced into the sinus. With an indian-rubber balloon introduced into the sinus, a distinct DE was found in the two sinuses examined when using the OSC-display. When using the LED- and GD-displays a BWE was found.

Table I. *The volumes and range of saline solution (ml) needed to obtain a distinct back wall echo (BWE) in 10 maxillary sinuses of autopsy specimens*

Specimen	OSC	LED	GD
I	2	5	2
II	3	5	5
III	1	3	2
IV	1	2	1
V	1	1	1
VI	1	2	2
VII	2	4	2
VIII	1	2	2
IX	2	3	2
X	2	4	2
Mean	1.6	3.1	2.1
Range	1-3	1-5	1-5
SD	0.70	1.37	1.10

* Paired t-test was used to establish whether or not there was a statistical difference between two sets of data.

DISCUSSION

In the actual study the results were identical when using transducer diameters of either 10 mm or 13 mm. According to Revonta (1980) a transducer diameter > 12 mm may give false positive echoes, but no such echoes were found when the 13 mm transducer was used in our experiments. No difference was found between the transducer frequencies of 2.25 MHz and 3.5 MHz, but from a theoretical point of view a frequency of 3.5 MHz is the best choice for maximum tissue penetration despite ultrasound attenuation (Holmer & Lindström, 1978). Therefore we recommend this frequency at sufficient transmission power for clinical purposes.

When biological tissue is examined there is always an attenuation of the ultrasound pulse which must be compensated for by amplification. In most commercial equipment the amplification is manually adjustable, but in the present equipment a fixed quasi-logarithmic amplification is used (Holmer & Lindström, 1978). This means that small echoes from structures far away from the transducer are amplified more than large echoes from structures close to the transducer. This makes the equipment easy to handle and the results obtained from repeated examinations as well as by different investigators can be directly compared. On the other hand, repetition echoes, that means echoes with exactly the same distance between their peaks, caused by rebounding of the ultrasound beam in the frontal wall, cannot always be eliminated. However, repetition echoes are easily separated from a real AME or BWE by storing the picture on the OSC- or GD-display.

The results obtained with all display units on plexiglass and bone models containing air or fluids are in accordance with earlier results (Gilbricht & Heidelberg, 1968; Kitamura et al., 1969; Jannert et al., 1980; Revonta, 1980). A total reflection of the ultrasound pulse (AME) indicates an air-filled sinus and the appearance of a BWE indicates a pathological sinusal content, usually increased amount of secretion. The ultrasound signal of the equipment used can penetrate solid bone of 16 mm and the shortest separable intrasinus distance is about 3-5 mm. This should permit reliable results also in frontal sinus examinations.

In our experiments on plexiglass boxes and bone models a fluid level of 2-3 mm was sufficient to give a distinct BWE which is in

accordance with the findings of Revonta (1980). In the human experiments a statistically significant difference of the detectable amount of saline was found between the OSC-display (mean 1.6 ml) and the LED-display (mean 3.1 ml) and also between the OSC-display (mean 1.6 ml) and the GD-display (mean 2.1 ml) but no statistically significant difference was found between the GD- and LED-displays in their capacity to detect fluid. The smallest detectable amount of secretion with radiography is about 5 ml but not until five projections have been used (Axelsson et al., 1970). Thus, in these experiments ultrasonography seems more sensitive than radiography in this respect, but this is not yet clinically verified.

When the head was tilted backwards the BWE disappeared on all the display units but returned when the head was replaced in an upright position. However, the value of this manoeuvre has to be tested clinically in order to find out if this procedure is reliable in clinical practice.

In the present study an artificial mucosal swelling ≥ 3 mm was detected on the oscilloscope (OSC) (Fig. 4:3). Revonta (1980) found that mucosal swelling of 1 mm was detected when using an Echoview VI. However, this is an expensive, technically complicated piece of equipment designed for abdominal and cardiological examinations and not for screening purposes of paranasal sinuses. Furthermore, the clinical value of being able to detect a mucosal swelling of 1 mm is questionable (Jannert et al., 1981c). An artificial mucosal swelling (gel) < 8 mm could not be detected with the LED- and GD-displays which is in accordance with Jannert et al. (1980) and Revonta (1980) who found that the LED-display was only useful when estimating heavy mucosal swelling. Gel on the back wall of the box indicating mucosal swelling could not be detected with any of the display units when the sinus model was filled with saline, due to the low acoustic impedance at the boundary between the "mucosa" and the saline. The AME at the frontal wall as well as the BWE were seen distinctly with the OSC when the sinus model was partially filled with saline. This is explained by the reflection of the ultrasound pulse in the boundary between the air and mucosa as well as in the back wall of the sinus.

The existence of a DE in cases of intrasinusal cysts has been noticed earlier by Kitamura et al. (1969) who tried to explain this phenomenon by one echo generated on the back wall of the cyst and a second on the sinusal back wall. This was confirmed in the model experiment. Double echoes were also found in concave surfaces directed towards the transducer. The first echo was found to be generated from the total reflection of the central part of the ultrasonic beam in the centre of the concave surface of the hemisphere. The second echo can be explained by a reflection of the lateral part of the beam which will find a longer way back to the transducer by multireflection. The distance between the peaks of the echoes indicates the difference in path length of the different parts of the ultrasound beam before reaching the transducer. Theoretically, a double echo may also be found in a sinus filled with secretion, where the walls of the sinus allow both a single reflection as well as a double reflection of the ultrasound beam. However, double echoes will most probably be found in cases with intrasinusal cysts as these have an ideal shape for multi-ultrasound wave reflection and a smooth surface which also enhances reflection. Similar problems were discussed for other tissue by Goldstein & Madrazo (1981). As a DE was invariably found in the actual experimental study when using the OSC the existence of a DE seems to indicate an intrasinusal cyst, but this has to be verified clinically.

In conclusion, the model experiments showed that all three units were capable of separating air from other types of sinusal contents. With the OSC-display artificial mucosal swelling (≥ 3 mm), fluid and cyst-like objects can be separated from each other. The smallest detectable amount of fluid was about 1 ml in human maxillary sinuses when using the OSC-display. With the LED- and GD-displays air could be separated from sinusal contents but saline solution and cyst-like objects could not be separated from each other. Artificial mucosal swelling could only be detected if it was thicker than 8 mm. A statistical difference ($p < 0.05$) was found in the minimum amount of saline solution detectable in human sinuses when using the OSC-display (mean 1.6ml) compared with the GD-display (mean 2.1 ml) and the LED-display (mean 3.1 ml). The GD-display can store the signals, which is an advantage compared with the LED-display which lacks this facility.

The reflected ultrasound echoes can easily be read on the GD-display even in bright day-light, while the LED-display needs a darkened room as the LED-signals are intensity-modulated.

These ultrasound systems and Sinoscan Proto (Revonta, 1980) are the first constructed and adapted especially for investigation of the paranasal sinuses. However, there is an important difference between the systems used in this study and Sinoscan Proto, as the latter is equipped with ordinary manual amplification. This increases the risk of unreliable results from the ultrasonic examination compared with results obtained with systems with quasi-logarithmic amplification. Using this solution, external controls for gain adjustment can be excluded and the equipment will be easier to handle and the results obtained for repeated examinations and by different investigators will be directly comparable. The OSC-display seems to be the best for scientific as well as for clinical purposes, while the others are more suited for screening purposes. The results obtained with the LED-display are in accordance with those reported for the Sinoscan Proto. However, our model experiments show that the GD-display is superior to the LED-display for screening purposes.

APPENDIX

THE PHYSICS OF ULTRASOUND

Reflection

A short ultrasound pulse is known to travel through human tissue with a sound velocity of about $1\,540\text{ m.s}^{-1}$ (Wells, 1969). This is the most widely used average velocity in modern ultrasound equipment. However, in the human body there are at least two structures, air and bone, whose acoustic properties are significantly different from those of soft tissue. The sound velocity (v) in air is 340 m.s^{-1} and in bone about $2500\text{--}4000\text{ m.s}^{-1}$ and their densities (ρ) are also quite different. The acoustic impedance (Z) for these two media therefore differs from that of soft human tissue. The amount of ultrasound amplitude reflection (R) is given by the equation:

$$R = \frac{v_1 \cdot \rho_2 - v_2 \cdot \rho_1}{v_1 \cdot \rho_1 + v_2 \cdot \rho_2} \quad (\text{Formula A})$$

The reflection coefficient R for normal human tissue varies around 1-10 %. But the reflection at tissue-air boundaries is total (the reflection coefficient is almost 1). At a boundary of tissue and bone there is also almost total reflection. This is the reason why no back wall echoes are found in an air-filled paranasal sinus.

Absorption

Another physical phenomenon is the absorption of the ultrasound intensity during its passage through human tissue. The absorption of ultrasound intensity mainly depends on the fact that

- 1) the mechanical energy of sound waves is converted into heat due to internal friction;
- 2) there is scattering by small particles and inhomogenities in the media; and
- 3) the reflection at boundaries between media of different acoustic impedance.

The ultrasound intensity as a function of distance can be written as;

$$I_x = I_0 \cdot e^{-2\alpha fx} \quad (\text{Formula B})$$

where the intensity $I_x = I_0$ at $x = 0$, α corresponds to the absorption of the tissue and f corresponds to the ultrasound frequency used. This equation explains why it is impossible to use very high frequencies since the absorption rapidly increases with frequency. The coefficient α may sometimes be dependent on frequency which therefore increases the ultrasonic absorption even more as a function of frequency. For details, see Hill (1978).

Divergence

The ultrasound beam diverges and becomes wider after a certain distance. The widening of the beam is given by the equation:

$$\sin \alpha = 0.61 \cdot \frac{\lambda}{r} \quad (\text{Formula C})$$

where α is the divergence angle, λ the wave length of sound and r the radius of the circular transducer. From this equation it is obvious that the use of high frequencies, which is equivalent to short wave length λ , gives a small divergence angle and thus a well defined beam. This desired property of the ultrasound beam is, however, neutralized by the fact that when the frequency increases, the ultrasound attenuation increases even more.

Refraction

When the ultrasonic waves travel across the boundary between two media with different sound velocities v_1 and v_2 , they will be refracted in the same way as other waves. The angles of incidence and refraction are ϕ_1 and ϕ_2 , respectively, and are given by the equation:

$$\frac{v_1}{\sin \phi_1} = \frac{v_2}{\sin \phi_2} \quad (\text{Formula D})$$

The sound velocity has small variations in soft tissue. The refraction phenomenon is sometimes seen behind cysts in soft tissue and used as a help to distinguish between cysts and tumours (Kossoff, 1978).

Angle error

If the reflecting surface is not perpendicular to the transmitter, a large part of the transmitted sound will not be reflected back to the transducer.

ZUSAMMENFASSUNG

Vereinfachte Ultraschallausrüstungen mit drei verschiedenen Registrierungssystemen (Oszilloskop OSC, Lichtdioden LED und Gasentladungsdisplay GD) wurden in Modellversuchen und mit Obduktionsmaterial getestet und verglichen.

Die Registrierungssysteme zeigten dieselbe Kapazität bei der Trennung von Luft und Flüssigkeit. Ein statistisch signifikanter Unterschied bestand bei der Menge Natriumchlorid, festgestellt mit OSC-Registrierungssystem (Mittelwert 1.6 ml), verglichen mit dem LED-Registrierungssystem (Mittelwert 3.1 ml) und mit dem GD—Registrierungssystem (Mittelwert 2.1 ml), bei menschlichen Nebenhöhlenexperimenten.

Künstliche Schleimhautanschwellung ≥ 3 mm wurde mit OSC entdeckt, während "Schleimhautanschwellung" < 8 mm nicht mit den anderen Registrierungssystemen entdeckt wurde. Experimentelle Zysten wurden entdeckt und von Natriumchlorid mit OSC in sowohl Modellen als auch menschlichen Experimenten getrennt, doch nicht mit den anderen Registrierungssystemen.

Diese experimentelle Studie zeigt, dass OSC in der klinischen Praxis in der Unterscheidung verschiedener pathologischer Verhältnisse wertvoll sein kann. Die anderen Registrierungssysteme können jedoch für Screening-Zwecke anwendbar sein.

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A COMPARISON BETWEEN DIFFERENT ULTRASONIC DISPLAY
TECHNIQUES, RADIOGRAPHY AND INVASIVE CONTROL FOR
DIFFERENT DISORDERS OF THE PARANASAL SINUSES

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Abstract. Three pieces of simplified ultrasound equipment adapted for investigation of the paranasal sinuses have been tested in a clinical investigation of 148 sinuses in comparison with radiography and invasive control. An oscilloscope (OSC), one single row of light emitting diodes (LED) and a gas discharge (GD) display were used as display units. No statistically significant difference was found between the different displays or radiography in their screening capacity. It was found that the OSC-display was significantly more reliable than the other displays and radiography in separating different pathological conditions.

Clinical examination of suspected diseases in the paranasal sinuses is an unreliable method as reported e.g. by Axelsson et al. (1978). Radiographic examination is more reliable, but one must be aware of the radiation risk to the eye lens at repeated exposures. Sinus lavage, aspiration or sinoscopy are other methods with a high degree of reliability, but they all involve a certain discomfort for the patient. Ultrasonic examination of the paranasal sinuses seems to be a method without these drawbacks, as ultrasound is painless and harmless.

The possibility of using ultrasound for this purpose was first brought up by Keidel (1947). Since then the method has been used by several investigators, e.g. Mann (1975) and Revonta (1980).

Three different display techniques - oscilloscope display (OSC), light emitting diodes (LED) display, and gas discharge (GD) display - earlier tested in model experiments (Holmer et al., 1982) were used in this study together with radiography on a series of maxillary and frontal sinuses with the following aims, viz.:

- to evaluate the capacity of the different display systems and radiography for screening purposes;
- to investigate the capabilities of the display systems in separating different kinds of sinus contents; and
- to compare the results obtained with the three display systems with those of radiography.

METHODS

For medical purposes the pulsed ultrasound echo method is used with frequencies above 1 MHz. The pulse is reflected when reaching a boundary between tissue of different acoustic impedances. For different media the impedance can be calculated from the equation: $\text{Sound Velocity (m.s}^{-1}) \cdot \text{Density (kg.m}^{-3}) = \text{Impedance (kg.m}^{-2}.\text{s}^{-1})$.

For detailed information about the basic physics of ultrasound, see Wells (1969) and Holmer & Lindström (1978). The reflected ultrasound pulses can be shown on different types of displays, which may consist of an oscilloscope, light emitting diodes, a gas discharge display or a liquid crystal display.

The oscilloscope display

Figure 1a shows the block diagram of the ultrasound equipment with the oscilloscope (OSC) display. The transmitter has a repetition frequency of about 1.2 kHz. This frequency is derived from the clock circuit, which also produces the millimetre and centimetre marker for the depth scale on the oscilloscope unit. The transmitted ultrasound pulse, which has a duration of a few μ -seconds, is produced by the transducer. The ultrasound pulse is reflected at the different boundaries in the body where the acoustic impedance changes. The echoes are then received by the same transducer (acting both as a transmitter and a receiver) and the signals are amplified by a quasi-logarithmic amplifier (Holmer & Lindström, 1978). The latter has no external controls for compensation of tissue attenuation. The demodulated signals are then displayed on an OSC together with the depth markers. The receiver is connected to a digital memory which makes it possible to "freeze" the picture. The depth scale can be changed from 3 to 14 centimetres.

The light emitting diodes display

The basic equipment is identical to that described above except that the display consists of an array of 40 light emitting diodes (LED) (see Fig. 1b). The diodes are intensity-modulated on the array in real time and each diode corresponds to a tissue depth of 1 or 2 mm. As the LED-equipment has no memory, the results of the display cannot be "frozen".

The gas discharge display

A simplified block diagram of the pulsed ultrasonic system with memory and gas discharge (GD) display (self-scanning display) is shown in Fig. 1c. The equipment consists of six "blocks". The first block activates a transmitter circuit causing the transducer to transmit a short ultrasound pulse. The reflected sound pulse is received by the same transducer. The signals are then amplified using the quasi-logarithmic amplifier. This signal is converted in a simplified A/D converter (6 comparators) and the digital values are stored in the memory. They are clocked (stored or written) into the memory at frequencies of 1.54 MHz and 0.77 MHz. These

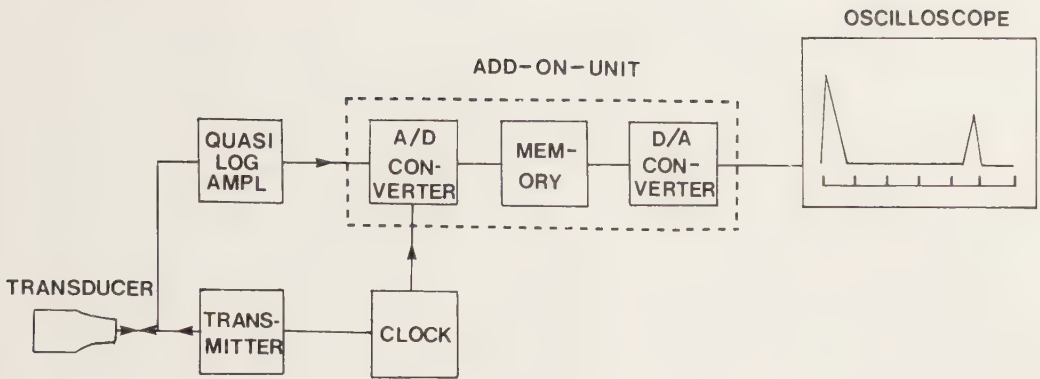


Fig. 1a. Block diagram of the equipment using an oscilloscope as the display unit.

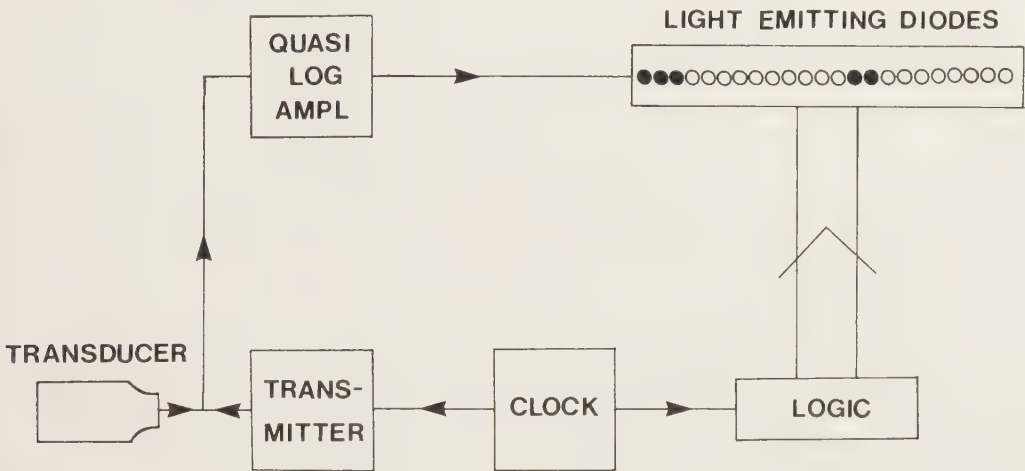


Fig. 1b. Block diagram of the equipment with a single row of light emitting diodes as the display unit.

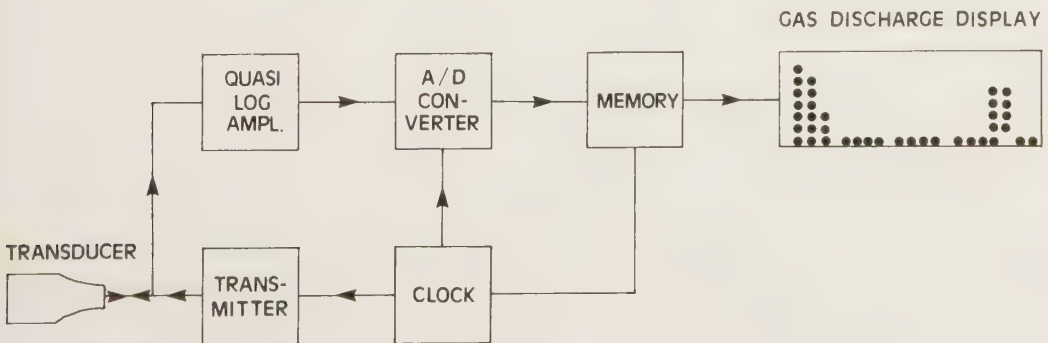


Fig. 1c. Block diagram of the equipment with a gas discharge display.

frequencies correspond to steps of 1 mm and 2 mm in human tissue, respectively, assuming the velocity of sound in tissue to be $1\,540\text{ m.s}^{-1}$. The digital value of the echo amplitude is then read out on the display at a lower frequency of 7 kHz (the upper frequency limit for the display). After each read-out cycle (111 columns have been shown), the transmitter is activated, and this results in a pulse repetition frequency of about 60 Hz. As the data are stored in the memory the display can be "frozen".

The transducer

A 3.5 MHz non-focused transducer has been used for all ultrasound examinations. The transducer has a diameter of 13 mm and is manufactured by Dapco*.

Documentation

In order to evaluate the results, the displays have been photographed with a Polaroid camera with an exposure time of 1/30 second when used for the OSC- and the GD-displays and 3 seconds when used for the LED-display.

Definition of echo types

Figure 2 shows the different types of echoes which are defined as follows:

Transducer pulse: The initial pulse wave within a depth of 1 cm read on the time scale (Fig. 2 a).

Air-mucosa echo (AME): The first real echo in an air-filled sinus (Fig. 2 b).

Repetition echoes: Echoes with exactly the same distance between their peaks but with decreasing intensity (Fig. 2 c) caused by the rebounding of the ultrasound beam in the frontal wall of the sinus.

Back wall echo (BWE): A single prominent echo at a distance of 4-6 cm (maxillary sinus) (Fig. 2 d) or at a distance of 2-3 cm

* Dapco Industries, Inc., Ridgefield Conn. 06877 U.S.A.

(frontal sinus) (Fig. 2 e) from the peak of the transducer pulse. (N.B. The distance scale is changed.) The BWE is preceded by an echo-free area of at least $1/3$ of the distance between the transducer peak and the BWE.

Double echo (DE): An echo consisting of 2 peaks at a distance of 4-6 cm from the transducer peak. The DE is preceded by an echo-free area of at least $1/3$ of the distance between the transducer peak and the DE (Fig. 2 f).

Ultrasonographic criteria used

Normal echogram (NE): An air-mucosa echo (AME) within 1.5 cm from the peak of the transducer pulse.

Mucosal swelling (MSW): The distance between the peak of the transducer pulse and the air-mucosa echo is 1.5-3.0 cm.

Secretion: The existence of a BWE.

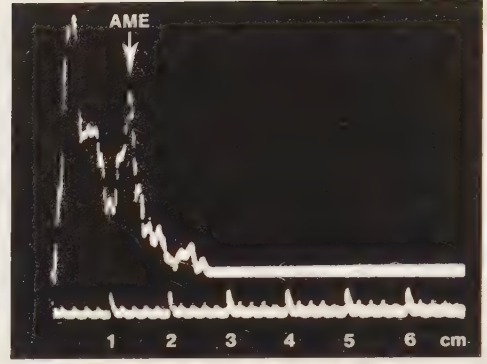
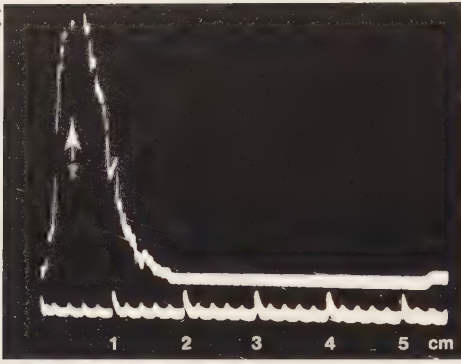
Intrasinusal cyst: The existence of a DE.

Radiography

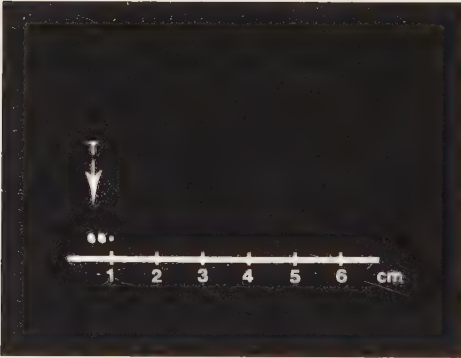
All radiographic examinations were performed at the Department of Diagnostic Radiology, Malmö General Hospital. Three standard projections (occipito-mental, occipito-frontal and lateral) were used. The radiographic findings were interpreted by the same radiologist and divided as follows:

1. Normal
2. Pathological
 - a. Mucosal swelling (a mucosal swelling with a depth of at least 2-3 mm but with central air within the sinus and no fluid level).
 - b. Total opacity (no signs of air within the sinus).
 - c. Fluid level (the existence of a horizontal border).
 - d. Mucosal cyst (a dome-shaped soft tissue shadow clearly delineated by air and with no or very small thickening of the mucosa covering the other parts of the sinus).

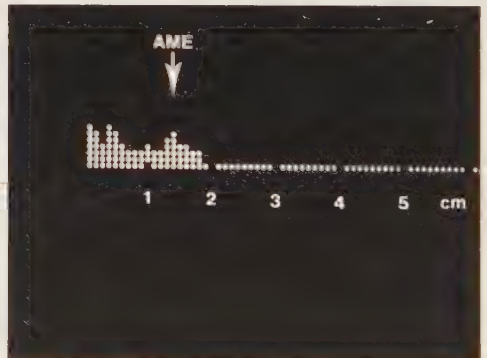
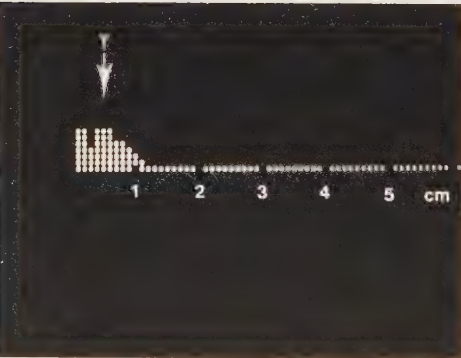
OSC



LED



GD



Transducer pulse (T)

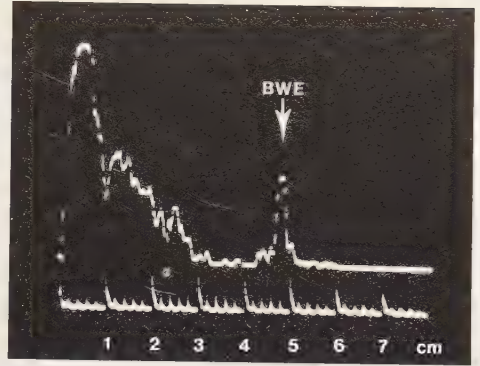
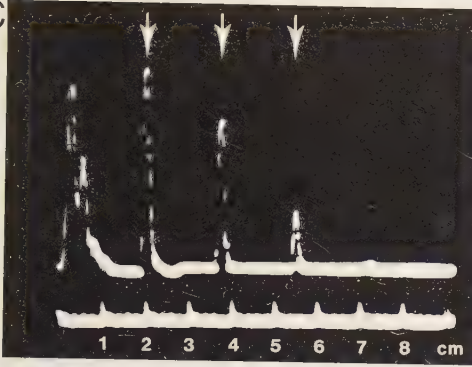
Air-mucosa echo (AME)

Fig. 2 a

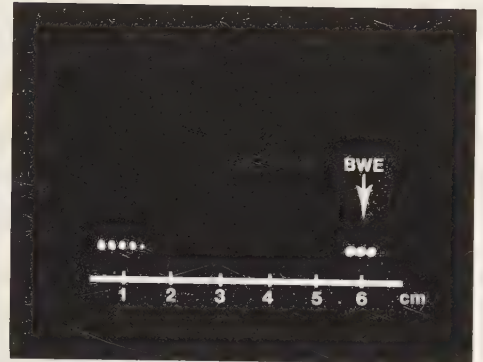
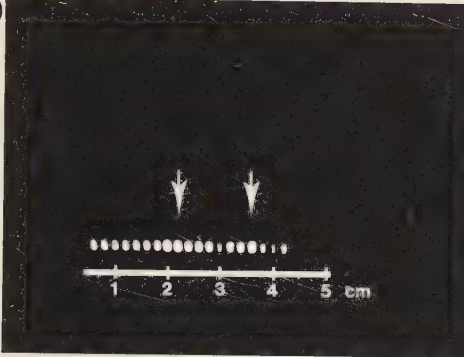
Fig. 2 b

Fig. 2. Different types of echoes with the three display techniques. For details, see text.

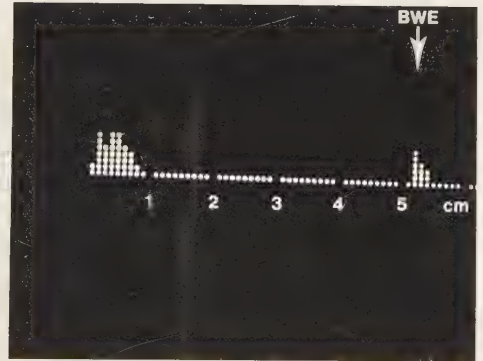
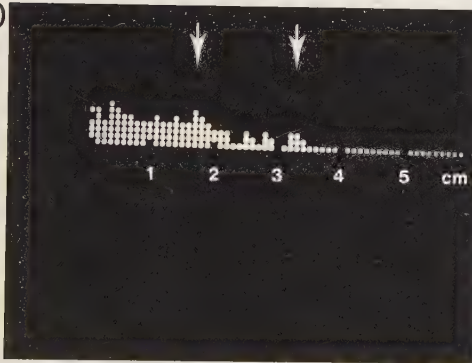
OSC



LED



GD

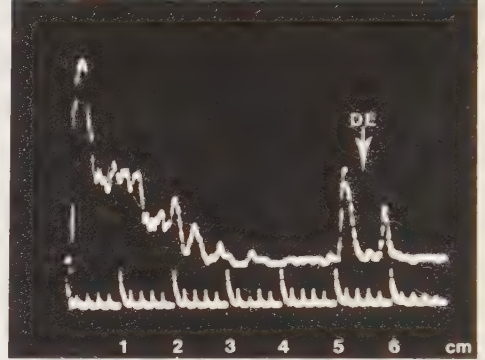
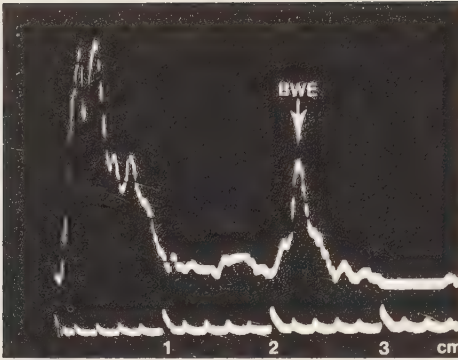


Repetition echoes

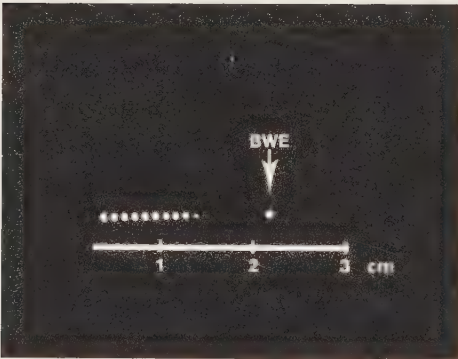
Back wall echo (BWE)
maxillary sinus*Fig. 2 c**Fig. 2 d*

Fig. 2 . Different types of echoes with the three display techniques. For details, see text.

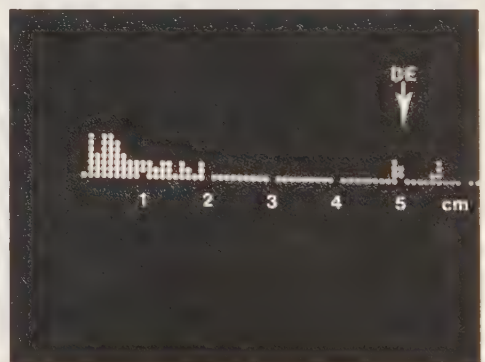
OSC



LED



GD



Back wall echo (BWE)
frontal sinus

Double echo (DE)
maxillary sinus

Fig. 2 e

Fig. 2 f

Fig. 2 . Different types of echoes with the three display techniques. For details, see text.

Invasive control

Puncture and irrigation. Under local anaesthesia (4 % lidocain-adrenalin) the nose was cleaned by suction and a trocar was inserted into the maxillary sinus via the inferior meatus. The sinus was irrigated with isotonic saline. When pus or mucus was clearly seen the sinus was classified as irrigation-positive.

Sinoscopy. Under local anaesthesia in the canine fossa a Storz endoscope was inserted into the maxillary sinus. The sinus was inspected with different optics (0° , 30° and 70° angles) and photographed. In 50 healthy cases a fiberscope (Olympus*) with an outer diameter of 1.7 mm was used for the sinoscopy.

Antrostomy. The maxillary sinus was explored via the canine fossa under general anaesthesia. Where cysts were found they were removed. The remaining mucosa was left intact if it seemed to be normal. In cases with chronic sinusitis a radical removal of all the mucosa was performed together with a wide opening to the nose in the inferior nasal meatus.

Trepanation of frontal sinus. The frontal sinuses were trephined under local anaesthesia. An incision of about 1 cm was made at the medial end of the eye-brow and the sinus was opened with a hole of 4 mm diameter. A drainage tube was inserted after which the wound was closed.

MATERIAL

The investigations were carried out on 138 maxillary sinuses in 91 persons (46 men and 45 women, aged 14-76, mean 37 years) and 10 frontal sinuses in 9 persons (7 men and 2 women, aged 22-39, mean 29 years). Eighty-eight maxillary sinuses and all the frontal sinuses were examined because of suspected disease. The remaining 50 maxillary sinuses were examined as part of an experimental investigation of the function of the maxillary ostium in healthy individuals (Jannert et al., 1982).

* ENF-P A1988, Olympus Corporation of America, 4 Nevada Drive, N.Y. 11042, U.S.A.

TEST PERFORMANCE

Immediately after the routine clinical ENT-examination all persons were investigated with the ultrasound equipment described above. No preparation of the patients except removal of false teeth was needed. The transducer was moistened with "Aquasonic"* gel in order to attain an air-tight contact between the transducer and the skin thereby diminishing the risks of artefacts. Ultrasound investigation was always performed in the sitting position.

The examined area was limited to a vertical plane through the lateral corner of the orbita (Fig. 3). Inferiorly the area was limited to a horizontal plane $\frac{1}{2}$ cm below the flow of the nasal cavity and superiorly to a horizontal plane 2 cm above the upper margin of the orbita. The medial limit was the lateral wall of the nasal cavity and the midline of the head. The head of the patient was supported by the hand of the examiner whereafter the transducer was placed just below the infraorbital nerve and the maxillary sinus was examined in horizontal and vertical directions. When examining the frontal sinus, the transducer was placed at the glabella and moved in a curve just below the eye-brow. In all cases the examination was performed on both sides. In sinuses showing a back wall echo re-examination after tilting the head was performed.

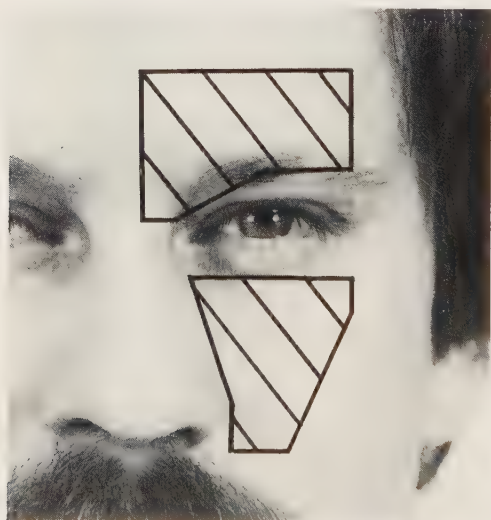


Fig. 3. The limits of the areas examined (dashed in the figure).

* Parker Laboratories, Inc., Orange, N.J. 07050 U.S.A.

The recordings started with the OSC-display. The echoes obtained on the oscilloscope were "frozen" and documented with a "Polaroid" camera. Then the LED-display was used and the echoes received were noted and, if possible, documented on Polaroid film. After that the examination was repeated with the GD-display and the display was photographed. The results of the clinical and ultrasound examinations were noted on the radiological questionnaire and the patients were directly sent for a radiological examination.

Invasive control was then carried out within 24 hours. Of the 148 sinuses, 100 were checked by sinoscopy, 27 by sinus lavage, 11 by explorative antrostomy and 10 by frontal trepanation.

RESULTS

Maxillary sinuses

Screening capacity. Of the 138 maxillary sinuses 60 were normal and 78 showed pathological changes during the invasive control. In Table I the results obtained with the different displays and radiography are correlated to the invasive findings judged as normal or pathological.

The findings using the OSC-display were concordant with normal invasive findings (to 98 %). In one sinus a BWE was found, probably due to the root of a tooth. With the LED- and GD-displays no false pathology was found, while radiography showed pathological changes in 2 sinuses. In one of these cases radiography showed total opacity, probably due to thick bony walls, and the other radiograph suggested a small amount of fluid which could not be verified invasively.

Of the 78 sinuses with pathological changes 75 (96 %) were detected with the OSC-display, 64 (82 %) with the LED-display, 68 (87 %) with the GD-display, and 73 (94 %) with radiography (Table I). There was no statistically significant difference between the capabilities of the different systems of distinguishing between normal and pathological sinuses ($p > 0.05^*$).

* All differences within the material have been tested with the critical ratio test.

Table I. *The capacity of the different displays and radiography to separate normal sinuses (N) from pathological ones (P) compared with invasive control.*

Invasive control	TESTS							
	OSC		LED		GD		X-RAY	
	N [*]	P ^{**}	N	P	N	P	N	P
N (60)	59	1	60	—	60	—	58	2
P (78)	3	75	14	64	10	68	5	73

* Normal sinuses

** Pathological sinuses

Specific diagnostic capacity. Table II shows the capacity of the three display units to separate different pathological conditions. Using invasive control, mucosal swelling (MSW) was found in 9 sinuses, secretion (secre) in 34 and cysts (cyst) in 35 sinuses.

Mucosal swelling was correctly diagnosed in 7/9 sinuses with the OSC-display and the corresponding figures for the LED- and GD-displays were 4/9 and 5/9, respectively. In the remaining cases the displays showed normal echograms (NE).

Secretion was correctly diagnosed with the OSC-display in 26/34 sinuses and in 30/34 sinuses with the LED- and GD-displays, which means no statistically significant difference ($p > 0.05$). In 2 sinuses mucosal swelling was suspected with all the displays and in 2 sinuses all the displays showed normal echograms. With the OSC-display a cyst was suspected in 4 sinuses but sinuscopy showed secretion.

Cysts were correctly diagnosed in 25/35 sinuses with the OSC-display and in 2/35 and 5/35 sinuses with the LED- and GD-displays, respectively. The differences between the OSC-display and both the other displays are statistically significant ($p < 0.01$). With the OSC-display secretion was suspected in 9 sinuses, all showing large cysts during sinuscopy, and in one

Table II. The capacity of the display units to separate different pathological conditions compared with invasive control.

Invasive control	TESTS											
	OSC				LED				GD			
	MSW	Secr	Cyst	NE	MSW	Secr	Cyst	NE	MSW	Secr	Cyst	NE
MSW 9	7	-	-	2	4	-	-	5	5	-	-	4
Secr 34	2	26	4	2	2	30	-	2	2	30	-	2
Cyst 35	-	9	25	1	-	26	2	7	-	26	5	4

sinus with a small cyst on the lateral wall of the sinus a normal echogram was found on the OSC-display. The LED- and GD-displays both showed secretion in 26/35 sinuses and normal echograms in 7/35 and 4/35 sinuses, respectively.

Altogether the OSC-display detected the pathology correctly in 58/78 (74 %) sinuses, while the LED-display did so in 36/78 (46 %) sinuses and the GD-display in 40/78 (51 %) sinuses. The difference between the OSC-display and the other display units is statistically significant ($p < 0.01$).

Table III shows the results of the radiographic examination compared with the invasive control. As can be seen from the table, 23 sinuses showed total opacity (opac) and as no corresponding group exists in Table II, direct comparison between ultrasound and radiographic results cannot be performed. Mucosal swelling was correctly diagnosed in 3/9 sinuses, secretion in 11/34 and cysts in 23/35 sinuses, respectively. In total, 37/78 (47 %) sinuses were correctly diagnosed with radiography.

Table III. *The capacity of radiography to separate different pathological conditions compared with invasive control.*

Invasive control	Radiography				
	MSW	Secr	Cyst	Opac	Normal
MSW 9	3	1	1	3	1
Secr 34	5	11	1	16	1
Cyst 35	5	1	23	4	2
Total	13	13	25	23	4

Table IV shows the results obtained with the different displays in 23 sinuses where radiography showed total opacity. The invasive control showed secretion in 16 sinuses, intrasinusal cysts in 4 and heavy mucosal swelling in the remaining 3. With the OSC-display mucosal swelling was suspected in 2 sinuses and this was invasively confirmed. Secretion was suspected in 16 sinuses, confirmed in 14, while heavy mucosal swelling was found in one and the remaining sinus contained a large cyst. A cyst was suspected with the OSC-display and invasively confirmed in 3 sinuses. In the 2 remaining sinuses, the OSC-display showed a normal echogram, while secretion mixed with air bubbles was seen during sinoscopy. With the LED- and GD-displays none of the cysts were detected; one sinus showed a correctly suspected mucosal swelling and the remaining findings were identical to those of the OSC-display. Altogether the results were concordant with the invasive control in 19/23 sinuses with the OSC-display and in 15/23 sinuses with both the LED- and GD-displays.

Frontal sinuses

All frontal sinuses showed purulent secretion during trepanation. In 9/10 sinuses all the three display systems showed secretion and in the remaining one the displays showed a normal echogram. This sinus showed total opacity using radiography. Radiography showed secretion or total opacity in 9/10 sinuses but in one case the radiograph was normal, while the displays all showed secretion.

Table IV. *The findings of the display units in 23 sinuses where radiography showed total opacity. Figures within brackets denote conformity with the invasive control.*

Displays	MSW	Findings			
		Secr	Cyst	NE	Correct
OSC	2(2)	16(14)	3(3)	2(0)	19
LED	1(1)	20(14)	-	2(0)	15
GD	1(1)	20(14)	-	2(0)	15

DISCUSSION

In almost all previous ultrasound studies of the paranasal sinuses the A-mode method has been used (Mann, 1975; Livshina et al., 1976; Mann et al., 1977; Edell & Isaacson, 1978; Revonta & Suonpää, 1979; Böckmann et al., 1981). The B-mode method is technically more advanced but does not offer any advantages for clinical routine use (Mann et al., 1976; Revonta, 1980). Earlier pieces of equipment with an oscilloscope as the display unit were not primarily constructed for investigation of the paranasal sinuses but Jannert et al. (1980) and Revonta (1980) both reported the use of a single row of light emitting diodes as a display unit for screening of the sinuses. In the present study three simplified pieces of mobile equipment (OSC-, LED- and GD-displays), earlier tested in model experiments (Holmer et al., 1982), have been clinically evaluated.

The diameter of the transducer is of importance as diameters < 8 mm may give false negative echoes and diameters > 12 mm may give false positive echoes (Revonta, 1980). However, no differences were found when transducers of 10 mm and 13 mm were tested in model experiments (Holmer et al., 1982). In the present study the larger transducer was used.

The frequency used was 3.5 MHz, which is an adequate compromise between tissue penetration and attenuation (Holmer & Lindström, 1978). In other studies frequencies between 2-6 MHz have been used (Kitamura et al., 1969; Mann et al., 1977; Edell & Isaacson, 1978; Revonta, 1980). In the present equipment a special quasi-logarithmic amplifier developed by Holmer & Lindström (1978) was used. Using this technique small echoes are more amplified than larger ones and therefore a high gain analysis is not needed. This modification makes the display units easy to handle and different examinations can be directly compared.

It is of importance to examine the whole area of the sinuses in different directions (Fig. 3) and special care must be directed towards the bottom of the sinus in order to detect small amounts of secretion. In model experiments the authors found that the present equipment showed a capacity to detect as small amounts as 1 ml of secretion (Holmer et al., 1982). However, one must be aware of false positive echoes which may arise from the teeth. In

two sinuses, where normal echograms were found, sinoscopy showed secretion mixed with air bubbles. This source of error has not earlier been reported. In our study no further information was obtained by tilting of the head, which is in accordance with Revonta (1980) who questioned the value of this manoeuvre.

The majority of the control tests were carried out with sinoscopy. Illum et al. (1972) found that sinoscopy was superior to radiography in 29 % of the cases in a group of 585 maxillary sinuses. However, they suspected that changes seen on the radiographs might have been overlooked in 9 % of the cases during sinoscopy. In their study metaoxedrine was used in order to reduce bleeding and in some cases there was a time-lag of some days between the radiological examination and sinoscopy. As all examinations were done within 24 hours in the present study and as neither metaoxedrine nor adrenaline was used these sources of uncertainty were eliminated.

There is a high incidence of intramaxillary cysts (35/138 cases) in our material compared with maxillary secretion (34/138 cases) or mucosal swelling (9/138 cases). The reason for this is that cases with acute sinusitis are usually conservatively treated, while most of the cases with other suspected diseases are routinely examined with sinoscopy in our department.

Considerably few investigations of invasively controlled cases have been reported so far. Mann (1977) and Revonta (1980) compared the capacity of ultrasound examination to detect secretion with sinus irrigation and they found a conformity in 90.2 % (256 sinuses) and 94 % (170 sinuses), respectively. In 143 sinuses, which were controlled with sinus irrigation, sinoscopy or antrostomy, Uttenweiler (1980) found conformity between the ultrasound findings and the invasive control in 89 % of the cases. When using the same display technique (oscilloscope) in the present study, 134/138 sinuses (97 %) were correctly judged as normal or pathological. With the LED- and GD-displays the corresponding figures were 124/138 (90 %) and 128/138 (93 %), respectively, and thus all pieces of equipment showed equal capability of separating "diseased" sinuses from healthy ones. This is in accordance with Revonta (1980) who found no significant difference between the OSC-display and the LED-display in their capacity to detect secretion.

With all the three display systems, secretion was detected in 9 out of 10 frontal sinuses and this is in accordance with Revonta (1980) who found conformity between ultrasound and invasive control in 19/20 sinuses.

As can be seen in Table II, mucosal swelling, secretion and cysts could be separated in 58/78 sinuses with the OSC-display compared with 36/78 using the LED-display and 40/78 with the GD-display. The difference between the oscilloscope and both the other displays is statistically significant ($p < 0.01$). According to this the LED- and GD-displays seem to be most suitable for screening purposes.

Radiography and the OSC-display showed equal capability of separating "diseased" from "non-diseased" sinuses, 95 % and 97 %, respectively ($p > 0.05$). However, the OSC-display was able to correctly detect different pathological conditions in 58/78 compared to 37/78 cases with radiography and this difference is statistically significant ($p < 0.01$).

Secretion was correctly detected in 26/34 (76 %) sinuses with the OSC-display (Table II), while the corresponding figures for radiography were 11/34 (32 %) (Table III). The difference is statistically significant ($p < 0.01$). Three standard projections were used and the results are in accordance with those of Axelsson et al. (1970) who found that secretion could be detected in 24 % when using four standard projections. When they added a fifth projection (occipito-mental-lateral) secretion could be detected in 88 % of the cases, which corresponds better to our results obtained with the OSC-display (76 %).

Out of the 35 cysts confirmed during the invasive control 25 (71 %) (Table III) were correctly detected with the OSC-display compared with 23 (66 %) with radiography (Table IV), which does not give a statistically significant difference ($p > 0.05$). Uttenweiler (1980) also found good conformity between radiography and ultrasound examinations in detecting maxillary cysts.

Vourinen et al. (1962) and Axelsson et al. (1970) reported total radiographic opacity as a sign of secretion in 86 % of cases, while Revonta (1980) found corresponding figures of 85 % in adults and 75 % in children. In the present study 23 sinuses were totally opaque. In 16 (70 %) of the sinuses sinuscopy revealed

secretion, in 4 (17 %) cysts and in 3 (13 %) mucosal swelling. With the OSC-display correct information on the sinusal content was obtained in 19/23 (82 %) sinuses. The corresponding figure for the other displays was 15/23 (65 %) and the difference was due to their inability to detect intrasinusal cysts.

In conclusion, this study indicates that the LED- and GD-display systems are only suitable for screening purposes, while the OSC-display system is a valuable, non-invasive method for clinical as well as scientific purposes.

ZUSAMMENFASSUNG

Drei vereinfachte Ultraschallapparate, die für die Untersuchung der Nasennebenhöhlen angepasst und mit Oszilloskop (OSC), Lichtdioden (Light Emitting Diodes - LED) und Gasentladungsddisplay (Gas Discharge Display - GD) ausgerüstet sind, wurden auf ein klinisches Material getestet, das 148 Nebenhöhlen umfasst. Das Ergebnis der Ultraschalluntersuchung ist mit einer entsprechenden Röntgenuntersuchung und invasiver Kontrolle verglichen worden. Zwischen OSC, LED, GD Displays und Sinus Röntgen bestand in der Screening Kapazität kein statistisch signifikanter Unterschied. Das Oszilloskop war aber statistisch signifikant besser als die übrigen Ultraschallapparate und Sinus Röntgen in seiner Fähigkeit zwischen verschiedenen pathologischen Zuständen in den Nasennebenhöhlen zu unterscheiden.

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